



Faculty of Resource Science and Technology

Systematic Study of Genus *Nepenthes* L. (Nepenthaceae) in Western Sarawak, Borneo

Nurul Nabilah Huda binti Mohd Hisham

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Systematic Study of Genus *Nepenthes* L. (Nepenthaceae) in Western
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Nurul Nabilah Huda binti Mohd Hisham

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DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.



Signature

Name: Nurul Nabilah Huda binti Mohd Hisham

Matric No.: 19020143

Faculty of Resource Science and Technology

Universiti Malaysia Sarawak

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ABSTRACT

Nepenthes is the sole genus of the monotypic family known as Nepenthaceae, under the order of Caryophyllales. This genus is native to Southeast Asia with Borneo and Sumatra being the centre of its diversity. *Nepenthes* are known as highly studied carnivorous plants for their unique morphological characteristics, ecology, carnivorous syndrome, ethnobotanical, phytochemical, and pharmacological properties. Hence, this study focused on revising and comparing the morphological characteristics of *Nepenthes* that are distributed particularly in western Sarawak as well as identifying the anatomical, micromorphological, and palynological characteristics of the *Nepenthes* studied. Distribution and ecology of each *Nepenthes* taxa were also studied. A total of eighteen taxa were recorded from western Sarawak (Samarahan, Kuching, Serian, and Samarahan). Most of the taxa were examined based on fresh samples collected from the field; *Nepenthes albomarginata*, *N. ampullaria*, *N. gracilis*, *N. hirsuta*, *N. hispida*, *N. mirabilis*, *N. mirabilis* var. *echinostoma*, *N. nazreeana* sp. nov. ined., *N. rafflesiana* and others. The remaining five taxa; *N. bicalcarata*, *N. northiana*, *N. veitchii*, *N. tentaculata*, and *N. x bauensis* were examined based on herbarium specimens deposited in SAR. The morphological examination revealed that the *Nepenthes* studied has interspecific and intraspecific variation among the taxa. The anatomical studies of 13 collected *Nepenthes* taxa under the light microscope were focused on two parts; the epidermal layers, and the midrib. The stomatal complex type of *Nepenthes* studied are all anomocytic either with straight, or sinuous type of anticlinal walls on their abaxial or adaxial surfaces. Additional data from Field Scanning Electron Microscopy revealed that the stomata have three types of formation; sunken, raised, and semi-raised. They are developed in various sizes and densities among the polygonal epidermal cells. The sessile glands also were noticed to appear mostly on the adaxial surfaces of leaves. Meanwhile, the midrib cross section

shows four types of outer shapes with different vascular bundle arrangements and have a complex closed vascular system with consistent closed, collateral vascular bundles. The micromorphological characteristics were observed mainly on the epidermal layers of the leaves, and the pitchers of *Nepenthes* under FESEM. Trichomes were present mostly on the abaxial surfaces of the leaves compared to the adaxial surfaces. More than five types of trichomes were identified and all of them were categorised into two which are glandular trichomes and non-glandular trichomes. The examination of the inner surface of the pitcher depicted a variety of features such as the lunate cells and the digestive glands. The lunate cells were found distributed abundantly on the upper part of the pitcher body which is known as the waxy zone. Ten taxa from the 13 *Nepenthes* studied own these features that are formed in a crescent-like shape which bends downwards and elongate horizontally in various lengths. Meanwhile, the digestive glands were observed present on the inner surface of the pitcher of all 13 *Nepenthes* studied. Most of them are developed in the basal half of the pitcher, known as the digestive zone. The digestive glands are conspicuously different in sizes and density among the 13 taxa studied. The palynological study focused on six *Nepenthes* taxa; *N. ampullaria*, *N. gracilis*, *N. mirabilis*, *N. nazreeana* sp. nov. ined., *N. rafflesiana*, and *N. reinwardtiana* are tetrahedral tetrad and inarpeturate with echinate-microechinate ornamentation. The sizes of the pollen tetrads of the six *Nepenthes* studied are slightly varied between 17.02-19.91 μm in diameter, and all of them were identified as small size which falls between 10-25 μm . The pollen characteristics are homogenous among the six *Nepenthes* taxa studied. Therefore, they are not possessing any taxonomic value that can help in delimiting the taxa in the genus. But, they can be differentiated by their sizes, which can be influenced by the environment or the methods used to observe the pollen.

Keywords: Borneo, Carnivorous plants, Caryophyllales, Malaysia, taxonomy

Kajian Sistematik Genus *Nepenthes* L. (*Nepenthaceae*) di Barat Sarawak, Borneo

ABSTRAK

Nepenthes merupakan genus tunggal dalam keluarga monotip yang dikenali sebagai *Nepenthaceae*, di bawah order *Caryophyllales*. Genus ini berasal daripada Asia Tenggara, dengan Borneo dan Sumatera menjadi pusat kepelbagaian. *Nepenthes* merupakan tumbuhan karnivor yang banyak dikaji kerana ciri morfologinya yang unik, ekologi, sindrom karnivor, sifat-sifat etnobotani, fitokimia, dan farmakologi. Oleh itu, kajian ini tertumpu kepada penelitian dan perbandingan ciri-ciri morfologi *Nepenthes* yang terdapat di bahagian barat Sarawak khususnya, serta mengenal pasti ciri-ciri anatomi, mikromorfologi dan palinologi *Nepenthes*. Taburan dan ekologi setiap takson *Nepenthes* turut dikaji. Sebanyak 18 taksa telah direkodkan dari barat Sarawak (Samarahan, Kuching, Serian, dan Samarahan). Kebanyakan taksa telah diperiksa berdasarkan sampel segar yang dikumpul daripada lapangan; *N. albomarginata*, *N. ampullaria*, *N. gracilis*, *N. hirsuta*, *N. hispida*, *N. mirabilis*, *N. mirabilis* var. *echinostoma*, *N. nazreeana* sp. nov. ined., *N. rafflesiana* dan lain-lain. Baki lima taksa; *N. bicalcarata*, *N. northiana*, *N. tentaculata*, *N. veitchii* dan *N. x bauensis* telah diperiksa berdasarkan spesimen herbarium SAR. Pemeriksaan morfologi mencirikan bahawa *Nepenthes* yang dikaji mempunyai variasi interspesifik dan intraspesifik dalam kalangan taksa. Kajian anatomi 13 taksa *Nepenthes* di bawah mikroskop cahaya tertumpu kepada dua bahagian; lapisan epidermis, dan pelepah. Semua *Nepenthes* yang dikaji mempunyai jenis kompleks anomositik sama ada dengan jenis dinding antiklinal lurus atau berliku pada permukaan abaksial atau adaksial. Data tambahan dari Mikroskop Elektron Pengimbasan Pelepasan Medan (FESEM) mencirikan stomata mempunyai tiga jenis pembentukan; tenggelam, timbul, dan separuh timbul dalam pelbagai saiz dan ketumpatan di kalangan sel epidermis poligon. Kelenjar sesil juga diperhatikan kebanyakannya muncul

pada permukaan adaksial daun. Keratan rentas pelepah pula menunjukkan empat jenis bentuk luar dengan susunan berkas vaskular yang berbeza dan mempunyai sistem vaskular tertutup yang kompleks dengan berkas vaskular cagaran tertutup secara konsisten. Ciri-ciri mikromorfologi diperhatikan terutamanya pada lapisan epidermis daun, dan periuk *Nepenthes* di bawah FESEM. Kebanyakan trikom terdapat pada permukaan abaksial daun berbanding permukaan adaksial. Lebih daripada lima jenis trikom telah dikenalpasti iaitu trikom kelenjar dan trikom bukan kelenjar. Pemeriksaan permukaan dalam periuk menggambarkan pelbagai ciri seperti sel lunat dan kelenjar pencernaan. Sel lunat didapati tersebar banyak di bahagian atas badan periuk yang dikenali sebagai zon berlilin. Sepuluh daripada 13 taksa *Nepenthes* yang dikaji memiliki ciri-ciri ini, berbentuk seperti bulan sabit yang membongkok ke bawah dan memanjang secara mendatar dalam pelbagai panjang. Sementara itu, kelenjar pencernaan diperhatikan terdapat pada permukaan dalaman periuk kera bagi kesemua 13 *Nepenthes* yang dikaji. Kebanyakannya dibangunkan di separuh bawah periuk, yang dikenali sebagai zon pencernaan. Kelenjar pencernaan berbeza dengan ketara dalam saiz dan ketumpatan antara 13 taksa yang dikaji. Kajian palinologi tertumpu kepada enam taksa *Nepenthes*; *N. ampullaria*, *N. gracilis*, *N. mirabilis*, *N. nazreeana* sp. nov. ined., *N. rafflesiana*, dan *N. reinwardtiana* ialah tetrad tetrahedral dan tidak terapetulasi dengan hiasan echinate-microechinate. Saiz tetrad debunga enam *Nepenthes* yang dikaji sedikit berbeza antara diameter 17.02-19.91 μm , dan kesemuanya dikenal pasti sebagai saiz kecil, antara 10-25 μm . Ciri-ciri debunga enam takson *Nepenthes* yang dikaji ialah homogen. Oleh itu, tidak mempunyai sebarang nilai taksonomi yang boleh membantu dalam membatasi taksa dalam genus. Tetapi, boleh dibezakan mengikut saiznya, yang dipengaruhi oleh persekitaran atau kaedah yang digunakan untuk memerhatikan debunga.

Kata kunci: Borneo, Caryophyllales, Malaysia, taksonomi, tumbuhan karnivor.

TABLE OF CONTENTS

	Page
DECLARATION	i
ACKNOWLEDGEMENT	ii
ABSTRACT	iii
ABSTRAK	v
TABLE OF CONTENTS	vii
LIST OF TABLES	xi
LIST OF FIGURES	xiii
LIST OF ABBREVIATIONS	xviii
CHAPTER 1 INTRODUCTION	1
1.1 Study Background	1
1.2 Problem Statement	3
1.3 Objectives	3
CHAPTER 2 LITERATURE REVIEW	4
2.1 The Carnivorous Plants	4
2.2 An Introduction of <i>Nepenthes</i> L.	6
2.3 The History of <i>Nepenthes</i> L.	7
2.3.1 The Discovery of <i>Nepenthes</i> L. in Borneo	10

2.3.2	The Discovery of <i>Nepenthes</i> L. in Sarawak, Borneo	15
2.4	Taxonomy of <i>Nepenthes</i> L.	19
2.4.1	Infrageneric Classification of <i>Nepenthes</i> L.	19
2.4.2	Hybridisation and Habitat Specificity in Genus <i>Nepenthes</i> L.	21
2.5	General Morphology of <i>Nepenthes</i> L.	23
2.5.1	The Leaves of <i>Nepenthes</i> L.	23
2.5.2	The Pitchers	24
2.5.3	The Inflorescences	25
2.6	Anatomical Study of <i>Nepenthes</i> L.	26
2.7	Palynological Study of <i>Nepenthes</i> L.	28
2.8	The Distribution of <i>Nepenthes</i> L.	31
2.9	The Interactions Between <i>Nepenthes</i> L. and Animals	32
	CHAPTER 3 MATERIALS AND METHODS	34
3.1	Sample Collection and Field Observations	34
3.1.1	Distribution	36
3.1.2	Habitat and Ecology	36
3.2	Preparation and Preservation of Herbarium Samples	37
3.3	Morphological Study	37
3.4	Micromorphological Study	39
3.4.1	Dehydration of Samples	39

3.4.2	Critical Point Drying (CPD)	40
3.4.3	Field Scanning Electron Microscopy Observation	41
3.5	Anatomical Study	42
3.5.1	Epidermal Cuticular Sectioning and Preparation	43
3.5.2	Midrib Transverse Sectioning and Preparation	43
3.5.3	Staining and Permanent Slide Preparation	44
3.5.4	Samples Observation Under the Compound Microscope	44
3.6	Palynological Study	45
CHAPTER 4 RESULTS AND DISCUSSION		47
4.1	Distribution	47
4.2	Habitat and Ecology	49
4.2.1	Habitat	49
4.2.2	Elevational distribution	53
4.2.3	pH and moisture of soil.	53
4.3	Morphology of <i>Nepenthes</i> L.	54
4.3.1	The Stem Morphology	54
4.3.2	Leaf Morphology	56
4.3.3	Pitcher Morphology	67
4.3.4	Type of Inflorescences	84
4.4	Anatomy	86

4.4.1	Leaf Surface	86
4.4.2	Midrib	95
4.5	Micromorphology	102
4.5.1	Stomata Formation	103
4.5.2	Trichomes	103
4.5.3	Lunate Cells and Digestive Glands	112
4.6	Palynology	121
4.6.1	Pollen Unit and Aperture	122
4.6.2	Pollen Size and Shape	123
4.6.3	Pollen Sculpturing	124
4.7	Species Treatment	127
4.7.1	General Description of Genus <i>Nepenthes</i> L.	127
4.7.2	Key to <i>Nepenthes</i> L. taxa studied in western Sarawak	129
4.7.3	Descriptions of 18 <i>Nepenthes</i> L. taxa studied	130
	CHAPTER 5 CONCLUSION AND RECOMMENDATIONS	190
5.1	Conclusions	190
5.2	Recommendations	193
	REFERENCES	194
	APPENDICES	207

LIST OF TABLES

	Page
Table 2.1: The carnivorous plant families and genera in the angiosperm groups (Thorogood, 2010)	5
Table 2.2: List of new <i>Nepenthes</i> taxa firstly discovered at Sarawak, Borneo	16
Table 2.3: The updated list of <i>Nepenthes</i> species in Sarawak	18
Table 2.4: Summarisation of pollen groups for 27 Bornean <i>Nepenthes</i> species with their pollen tetrad means diameter derived by Adam and Wilcock, 1999	30
Table 3.1: The structures and parameters of <i>Nepenthes</i> morphological descriptions based on Cheek and Jebb (1997), Clarke et al. (1997), Cheek and Jebb (2001), and Thorogood (2010)	38
Table 3.2: Selected structures of 13 <i>Nepenthes</i> studied observed under the FESEM	39
Table 3.3: Selected structures and parameters for micromorphological analysis	42
Table 3.4: The structures and parameters of <i>Nepenthes</i> anatomical analysis	45
Table 4.1: Ecology of <i>Nepenthes</i> in western Sarawak	52
Table 4.2: The morphological characteristics of <i>Nepenthes</i> stem	55
Table 4.3: Leaf morphological characteristics of <i>Nepenthes</i> studied in western Sarawak	59
Table 4.4: Characteristics of petiole and leaf attachment in <i>Nepenthes</i> studied	63
Table 4.5: Lid morphology of <i>Nepenthes</i> studied	80
Table 4.6: Comparison of stomatal characteristics of 13 <i>Nepenthes</i> studied (Nabilah Huda et al., 2022)	87
Table 4.7: Informal classification of 13 <i>Nepenthes</i> studied based on the stomatal density	90
Table 4.8: Vascular bundles arrangement in selected 13 <i>Nepenthes</i> taxa studied in western Sarawak	98
Table 4.9: Micromorphological characteristics of trichomes distributed on <i>Nepenthes</i> leaves	106

Table 4.10: The micromorphological characteristics of lunate cells in <i>Nepenthes</i> taxa	113
Table 4.11: Density and average sizes of digestive glands at the inner surface of the lower part of the pitcher in <i>Nepenthes</i> studied	117
Table 4.12: Pollen tetrad size of six <i>Nepenthes</i> studied in western Sarawak	123

LIST OF FIGURES

	Page
Figure 2.1: <i>Nepenthes madagascariensis</i> Poir. (taken from Clarke et al., 2018a)	8
Figure 2.2: Illustration of <i>Nepenthes distillatoria</i> L. (taken from Loddiges, 1827)	9
Figure 2.3: A painting of <i>Nepenthes northiana</i> Hook. f. by botanical artist, Marianne North, from the limestone hills of Bau, Kuching, Sarawak (Phillips et al., 2008)	14
Figure 2.4: Beautiful paintings by botanical artist, Marianne North are displayed in the Marianne North Gallery at Kew Gardens	15
Figure 2.5: Leaf morphology of <i>Nepenthes</i> L. adopted from Thorogood (2010); A. lanceolate leaf blade; B. spatulate leaf blade; C. obovate leaf blade; D. acutely-tapered apex; E. gradually-tapered apex; F. peltate apex; G. deccurrent at the base; H. Ssmi-clasping at the base; I. wholly clasping at the base; J. apetiolate; K. narrowly petiolate; L. broadly petiolate	24
Figure 2.6: Gross anatomy of <i>Nepenthes</i> pitcher (taken from Thorogood, 2010)	25
Figure 2.7: The treeshrews are defecating into pitchers of the three giant montane <i>Nepenthes</i> species while licking the nectar secreted by the glands developed under the pitcher lid (taken from Thorogood, 2010)	33
Figure 3.1: Location of Sarawak state in the map of Malaysia (taken from Nations Online, n.d.)	35
Figure 3.2: Map of Sarawak, Borneo, Malaysia	35
Figure 3.3: A. Critical Point Dryer (Brand Quorum/K850) with various key features to help the drying process of the samples for Field Emission SEM purposes. B. The chamber insert and the sample carrier, O-rings consist of 12 individual wells	41
Figure 4.1: Distribution map of <i>Nepenthes</i> studied in western Sarawak	48
Figure 4.2: Number of <i>Nepenthes</i> taxa based on habitats	50
Figure 4.3: Leaf Shapes of <i>Nepenthes</i> studied. (a) oblong (b) elliptic (c) spatulate (d) oblanceolate (e) obovate (f) lanceolate. Illustration by Nabilah Huda, M. H.	57
Figure 4.4: Leaf apex of <i>Nepenthes</i> studied. (A) acute (b) acuminate (c) obtuse (d) retuse (e) emarginate (f) sub-peltate. Illustration by Nabilah Huda, M. H.	62

Figure 4.5: Leaf base attachments of <i>Nepenthes</i> studied. (a) half clasping of the stem circumference at the base (b) $\frac{3}{4}$ clasping at the base (c) amplexicaul (d) leaf decurrent into the stem at the base (e) sub-perfoliate (f) petiole with saddle-like wings shape. Illustration by Nabilah Huda, M. H.	65
Figure 4.6: Type of margin in <i>Nepenthes</i> . (a) Entire margin (b) Fimbriate margin	66
Figure 4.7: (A-D) Intraspecific variation in lower pitcher plant of <i>Nepenthes rafflesiana</i>	69
Figure 4.8: (A-D) Intraspecific variation in upper pitcher plant of <i>Nepenthes rafflesiana</i>	70
Figure 4.9: Intraspecific variation within the <i>Nepenthes</i> taxa studied. (A) LP of <i>N. albomarginata</i> (B) UP of <i>N. albomarginata</i> (C) LP of <i>N. hirsuta</i> (D) UP of <i>N. hirsuta</i> (E) UP of <i>N. nazreeana</i> sp. nov. ined. (F) LP of <i>N. nazreeana</i> , (G) LP of <i>N. mirabilis</i> (H) UP of <i>N. mirabilis</i> . LP = Lower Part, UP = Upper Part	71
Figure 4.10: The slender shape of three <i>Nepenthes</i> taxa studied. (A) <i>N. albomarginata</i> (B) <i>N. gracilis</i> (C) <i>N. reinwardtiana</i>	72
Figure 4.11: Examination of natural hybrids of <i>Nepenthes</i> pitchers studied insitu. (A) <i>N. x hookeriana</i> , (B) <i>N. x trichocarpa</i> (C) <i>N. x kuchingensis</i>	74
Figure 4.12: General peristome structure of <i>Nepenthes</i> studied (a) Inner edge of the peristome with teeth (b) radial ridges or ribs of peristome (c) the overlapping epidermal cells (d) tooth like projection with the nectar pores. RR = Radial Ridges, NG = Nectar Gland, Arrow = Direction towards the inner pitcher. Magnification a = x100, scale bar = 100 μ m, b and d = x250, scale bar = 100 μ m, c = x500, scale bar = 50 μ m	76
Figure 4.13: (A) Peristome thorns of <i>N. bicalcarata</i> (B) SEM images of apex of peristome thorn with opening of nectar duct in <i>Nepenthes bicalcarata</i> (taken from Marlis et al., 1999)	78
Figure 4.14: Diagram of type of inflorescences. (A) Raceme or racemose (B) Panicle (adapted from Yingying et al., 2014)	85
Figure 4.15: The inflorescences of <i>Nepenthes</i> . (A) Male flowers (B) Female flowers	85
Figure 4.16: Illustration of anomocytic or ranunculaceous stomatal complex type. GC = Guard Cells, AW = Anticlinal Wall, SC = Subsidiary Cell, EC = Epidermal Cell. Illustration by Nabilah Huda, M. H.	88
Figure 4.17: Straight anticlinal walls on the abaxial (a1-f1), and adaxial surfaces (a2-f2) of leaves in <i>Nepenthes</i> studied. (a) <i>N. mirabilis</i> (b) <i>N. mirabilis</i> var. <i>echinostoma</i> (c) <i>N. nazreeana</i> sp. nov. ined. (d) <i>N. rafflesiana</i> (e)	

<i>N. reinwardtiana</i> (f) <i>N. x hookeriana</i> . Magnification 400×, scale bar = 100 µm	91
Figure 4.18: Sinuous anticlinal walls on the abaxial (a1-c1), and adaxial surfaces (a2-c2) of leaves in <i>Nepenthes</i> studied. (a) <i>N. gracilis</i> (b) <i>N. hispida</i> (c) <i>N. x kuchingensis</i> . Magnification 400×, scale bar = 100 µm	93
Figure 4.19: Sinuous anticlinal walls on the abaxial (a1-c1), and straight anticlinal walls on the adaxial surfaces (a2-c2) of leaves in <i>Nepenthes</i> studied. (a) <i>N. albomarginata</i> (b) <i>N. ampullaria</i> (c) <i>N. hirsuta</i> . Magnification 400×, scale bar = 100 µm	94
Figure 4.20: Type of midrib outer shape in selected 13 <i>Nepenthes</i> studied. AD = Adaxial surface, AB = Abaxial surface	96
Figure 4.21: Characteristics of vascular bundle in <i>Nepenthes</i> studied. Pc = Parenchyma Cell, Ph = Phloem, Sc = Sclerenchyma, Xy = Xylem. Magnification = 200x, Scale Bar = 200 µm	97
Figure 4.22: Transverse section of midribs of 13 <i>Nepenthes</i> studied shows a complex vascular system, with a closed ring system (a) <i>N. albomarginata</i> (b) <i>N. ampullaria</i> , (c) <i>N. gracilis</i> (d) <i>N. hirsuta</i> (e) <i>N. hispida</i> (f) <i>N. mirabilis</i> Magnification = 40x, Scale bar = 1000 µm	100
Figure 4.23: Stomata formation of the <i>Nepenthes</i> studied at the lamina surfaces. (a) Raised stomata (b) Semi-raised stomata (c) Sunken stomata. Magnification = x1800	103
Figure 4.24: Type of trichomes of 13 <i>Nepenthes</i> studied in western Sarawak. (a-d) variation of peltate glandular trichomes (e) capitate glandular trichome (f) scale trichome (g) long simple, unicellular trichome with smooth surface, branched at the base (h) simple, long unicellular trichome with scale surface (i) Simple, short unicellular trichome, with smooth surface (j-l) variation of stellate rotate trichomes. Magnification a-l = x100 – x2000	104
Figure 4.25: FESEM of abaxial and adaxial surfaces of leaves in <i>Nepenthes</i> studied. (a) <i>N. albomarginata</i> (b) <i>N. ampullaria</i> (c) <i>N. gracilis</i> . a1-c1 (Abaxial), b2-c3 (Adaxial). Magnification a-c = x100, scale bar = 100 µm	108
Figure 4.26: Inner surface of the pitcher in <i>Nepenthes</i> studied. (a) Lunate cell in the upper part of the pitcher below the peristome is covered with crystal wax. (b) Mature digestive glands half-sink towards the ‘hood’. Magnification a = x2000, scale bar = 10 µm, b = x350, scale bar = 50 µm	113
Figure 4.27: Lunate cells in the pitcher of <i>Nepenthes</i> studied. (a) <i>N. albomarginata</i> (b) <i>N. gracilis</i> (c) <i>N. hirsuta</i> (d) <i>N. mirabilis</i> (e) <i>N. mirabilis</i> var.	

<i>echinostoma</i> (f) <i>N. nazreeana</i> sp. nov. ined. Magnification a-e = x250, f = x200	115
Figure 4.28: Digestive glands of <i>Nepenthes</i> studied. (a) <i>N. albomarginata</i> (b) <i>N. ampullaria</i> (c) <i>N. gracilis</i> (d) <i>N. hirsuta</i> (e) <i>N. hispida</i> (f) <i>N. mirabilis</i> (g) <i>N. mirabilis</i> var. <i>echinostoma</i> (h) <i>N. nazreeana</i> sp. nov. ined. Magnification a-g = x100, h = x150	119
Figure 4.29: Male flowers of <i>Nepenthes</i> . (a) anther without the pollen grains (b) matured pollen grains abundantly produced within the anther of the flower (c) observation of the anther part under the Field Scanning Electrion Microscopy (FESEM) (d) close up view of pollen grains produced by the anther. Magnification c = x50, scale bar = 500 µm, d = x250, scale bar = 100 µm	121
Figure 4.30: Pollen grains of <i>Nepenthes</i> studied. (a) equitorial view of pollen grains that shows tetrahedral tetrad unit of pollen (b) polar view of pollen. Magnification a = x4500, scale bar = 5 µm, b = x4000, scale bar = 5 µm	122
Figure 4.31: Pollen sculpturing. (a) (b) sporoderm of the pollen. Magnification a-b = x20000, scale bar = 1 µm	124
Figure 4.32: Pollen tetrad of six <i>Nepenthes</i> studied. (a) <i>N. ampullaria</i> (b) <i>N. gracilis</i> (c) <i>N. mirabilis</i> (d) <i>N. nazreeana</i> sp. nov. ined. (e) <i>N. rafflesiana</i> (f) <i>N. reinwardtiana</i> . Magnification a-f = x4000, scale bar = 5 µm	126
Figure 4.33: Herbarium specimen of <i>Nepenthes bicalcarata</i> . Sarawak, Sri Aman Division, Betong, Saribas FR, peat swamp forest, 13 Aug 1957, Anderson, J. A. R., S8533 (SAR)	140
Figure 4.34: Herbarium specimen of <i>Nepenthes bicalcarata</i> . Sarawak, Kuching Division, Loba Kara, 16 Apr 1954, Anderson, J. A. R., S2820A (SAR)	141
Figure 4.35: <i>Nepenthes nazreeana</i> sp. nov. ined. insitu. (A) Habitat of the species. (B) The upper pitcher form (B) The lower pitcher form	159
Figure 4.36: Herbarium specimen of <i>Nepenthes northiana</i> Hook. f. Borneo, Malaysia, Sarawak, Kuching division, Tebedu, Mile 15 th , 6 February 1985, Abg, Mokhtar et al., S49230, SAR	163
Figure 4.37: Herbarium specimen of <i>Nepenthes northiana</i> Hook. f. Borneo, Malaysia, Sarawak, Kuching Division, Bau, Gunung Ropih, 11 Dec 2001, Shaevy et al., SBC2412, SAR	164
Figure 4.38: Herbarium specimen of <i>Nepenthes tentaculata</i> Hook. f. Sarawak, Kuching Division, Lundu, Gunung Berumput, 25 August 1960, Smythies, B. E., S13153 (SAR)	175

- Figure 4.39: Herbarium specimen of *Nepenthes tentaculata* Hook. f. Sarawak. Borneo, Malaysia, Sarawak, Kuching Division, Lundu, Gunung Kanyi, 27 April 1984, *Dyg. Awi & Paie, T.*, S47331 (SAR) 176
- Figure 4.40: Herbarium specimen of *Nepenthes veitchii* Hook. f. Sarawak, Kuching division, Santubong, 23 August 1957, *T.C.W and Anderson, J. A. R.* S8421 (SAR) 179
- Figure 4.41: Herbarium specimen of *Nepenthes veitchii* Hook. f. Sarawak, Kuching Division, Santubong, 21 December 1975, *Stevens, P. F. P.F Stevens* 317 (SAR) 180
- Figure 4.42: Herbarium Type specimen of *Nepenthes x bauensis* Chien C. Lee. Sarawak, Kuching Division, Bau, Gunung Umbut, 26 March 2002, *Meekiong, K.*, SBC 2701 (SAR) 183

LIST OF ABBREVIATIONS

Abax	Abaxial
Adax	Adaxial
C.	Around or about
CGS	Centre for Graduate Studies
cm	Centimeter
DA	Disturbed Areas
DF	Disturbed Forest
FESEM	Field Scanning Electron Microscopy
FOV	Field of View
FR	Forest Reserve
GPS	Geographic Coordinate System
HUMS	Herbarium of Universiti Malaysia Sarawak
KF	Kerangas Forest
LDF	Lowland Dipterocarp Forest
LF	Limestone Forest
m	Meter
m.a.s.l	Meter above the sea level
MDF	Mixed Dipterocarp Forest
mm ²	Squared meter
Mt.	Mount
N/A	Not Available
NH	Prefix cord of herbarium specimen for Nabilah Huda
NP	National Park

pH	Potential of Hydrogen
PSF	Peat Swamp Forest
SAR	Herbarium of Sarawak Forest Department
SEM	Scanning Electron Microscopy
SF	State Land Forest
SP	Sandstone Plateau
UNIMAS	Universiti Malaysia Sarawak
UP	Upper pitcher plant
LP	Lower pitcher plant
µm	Micrometer
°C	Degree celcius
%	Percentage

CHAPTER 1

INTRODUCTION

1.1 Study Background

The diversity of *Nepenthes* can be found mostly scattered in Malesia Region (Cheek & Jebb, 2001). Many of them are endemic to Borneo island which include Malaysia (Sabah and Sarawak), Brunei as well as Indonesia (Sumatra). *Nepenthes* preferred to grow in soil that is alkaline, acidic and lacking in nutrients mainly Nitrogen which leads them to be carnivorous (Handayani, 2017). Amazingly, they adapted well to that condition by deriving nutrients using their unique morphological characteristic which is the modified leaf tip to attract, trap and digest the prey mainly insects (Adam, 1997; Mithofer, 2011).

Nepenthes L. was first described and formally published by Carl Linnaeus in 1753 which then *Nepenthes distillatoria* L., a species from Sri Lanka referred to as type specimens for the genus (Linnaeus, 1753). Phillipps et al. (2008) described that the *Nepenthes* can grow to more than one meter and carries a vase-like shape of a hollow flower or fruit in red or yellow colour with its lid. Also, they have modified leaves that are often known by various names such as jugs, little bags, pots, urns, jurns, tankards, flasks, beakers, mugs and stomachs (Phillipps et al., 2008). Their seeds are usually dispersed by wind and can travel not so far (Clarke, 1997).

Clarke and Lee (2004) stated that new species of *Nepenthes* L. are being described each year which contributes to the increasing number of species in this genus. Despite that, their population are declining due to overharvested of the plant and deterioration of their habitat. Now, many of the species are threatened with extinction. *Nepenthes* are

economically important as they are collected for preparing foods and medicine as well as ornamentals in domestic collections (Rizqiani et al., 2018). These activities have caused too many problems which then various initiatives and actions are being taken to conserve it.

In taxonomy, the genus *Nepenthes* L. is problematic at the infrageneric level and it was taxonomically challenging to delineate the *Nepenthes* taxa due to their high level of intraspecific variability and polymorphisms, extreme heterophylly and a bias in the selection of herbarium material for extreme forms (Thorogood, 2010). Past monographic revisions of *Nepenthes* L. by Hooker (1873), Macfarlane (1908) and Danser (1928) have not fully resolved the family. The extreme heterophylly in the genus *Nepenthes* L. can be seen by the production of morphologically distinct lower and upper pitchers of the same species (Thorogood, 2010). Thus, the identification of *Nepenthes* species in the field must consider other characteristics including the morphology of the lid and peristome as well as the characteristics of the leaves and stems and not solely depend on the pitcher shape and colouration.

So, these present studies are aimed to revise the taxonomy of *Nepenthes* L. distributed in western Sarawak and identify the morphological, anatomical and palynological characteristics that could be useful data to differentiate those species. Other than that, this study also aimed to describe and documented its ecology and distribution in the selected region. This study will be focusing on the *Nepenthes* species that are distributed in western Sarawak which included several divisions such as Kuching, Samarahan, Serian and Sri Aman.

1.2 Problem Statement

The relationship and differences between most of the taxa in the genus of *Nepenthes* are taxonomically challenging as they have a high level of intraspecific variability and polymorphism, an intense heterophylly and a bias in the selection of herbarium materials (Thorogood, 2010). Other than that, there are limited information and descriptions of the micromorphological, anatomical, and palynological characteristics of *Nepenthes*, especially in western Sarawak, Borneo, Malaysia. Therefore, it is very important to revise the taxonomy of *Nepenthes* species that are distributed in western Sarawak and identify other systematic characteristics through micromorphology, anatomy, and palynology to aid in delimiting the taxa in the genus. Along with that, it is also crucial to record the current distribution of *Nepenthes* and describe the ecological characteristics of the taxa that exist particularly in western Sarawak.

1.3 Objectives

The aims of this study were as follows:

1. To identify and revise the taxonomy of *Nepenthes* taxa and its characteristics that differentiate the taxa in western Sarawak.
2. To describe the distribution and ecology of *Nepenthes* taxa in western Sarawak.

CHAPTER 2

LITERATURE REVIEW

2.1 The Carnivorous Plants

Givnish (2015) stated three criteria of the plant that are considered carnivorous which are, they must be able to ingest nutrients from the dead body of prey nearby to its surface, acquire some benefits in growth or reproduction and have unequivocal adaptations for dynamic prey attraction, capture and digestion. Presently, there are a total of 11 families and 19 genera of the carnivorous plant recognised from four angiosperm groups (Asterids, Rosids, Core Eudicots and Monocots) in the world (Table 2.1) (Heubl et al., 2006; Thorogood, 2010). They uniquely evolved and portrayed degrees of convergence and divergence of morphological traits among the carnivorous plant for their adaptations depend on their ecological factors (Ellison & Gotelli, 2001; Thorogood, 2010; Thorogood et al., 2017). For instance, Thorogood (2010) mentioned that the three families Sarraceniaceae, Nepenthaceae and Droseraceae were classified in the artificial order, Sarraceniales based on the morphological adaptations to the carnivorous syndrome. Notwithstanding, the Nepenthaceae and Droseraceae have been moved to the order Caryophyllales based on the evidence of the carnivory evolution through phylogenetic analysis and revised morphological data (Thorogood, 2010).

Table 2.1: The carnivorous plant families and genera in the angiosperm groups (Thorogood, 2010)

Angiosperm Group	Order	Family	Genus
Asterids	Lamiales	Byblidaceae	<i>Byblis</i>
		Martyniaceae	<i>Ibicella</i>
		Lentibulariaceae	<i>Pinguicula</i> <i>Genlisea</i> <i>Utricularia</i>
	Ericales	Roridulaceae	<i>Roridula</i>
		Sarraceniaceae	<i>Sarracenia</i> <i>Heliamphora</i> <i>Darlingtonia</i>
	Asterales	Stylidiaceae	<i>Stylidium</i>
Rosids	Oxidales	Cephalotaceae	<i>Cephalotus</i>
Core Eudicots	Caryophyllales	Dioncophyllaceae	<i>Triphyophyllum</i>
		Drosophyllaceae	<i>Drosophyllum</i>
		Nepenthaceae	<i>Nepenthes</i>
	Caryophyllales	Droseraceae	<i>Aldrovandra</i> <i>Dioneaea</i> <i>Drosera</i>
			<i>Brocchinia</i> <i>Catopsis</i>
Monocots	Arecales	Bromeliaceae	

The order Caryophyllales has the most carnivorous plant family in it. This order is also known as Centrospermae which means ‘with the seeds in the centre’ and has been identified as a major natural group within the angiosperms (Bittrich, 1993; Cuenoud, 2003). Cuenoid (2003) claimed that most of the members in the order Caryophyllales can adapt very well to extreme habitats such as xeric conditions, nitrogen-poor nutrient soil and saline soils. The carnivorous plants of Droseraceae, Dioncophyllaceae, Drosophyllaceae and Nepenthaceae are part of the Caryophyllales members that can survive amazingly in nitrogen-poor soils.

2.2 An Introduction of *Nepenthes* L.

Nepenthes L. is a sole genus of a monotypic family named Nepenthaceae under the order of Caryophyllales (Moran & Clarke, 2010). *Nepenthes* is a tropical pitcher plant and a carnivorous plant that is commonly known as *Periuk Kera* (Malay), *Entuyud* (Iban), *Tilambuo*, *Trambuo* (Bidayuh), and *Sawan Ndo'* (Penan) in Malaysia. Interestingly, as mentioned by Phillips et al. (2008), the name of *Nepenthes* was established by a famous Swedish botanist, Carl Linnaeus in the year 1737 in his writing of *Hortus Cliffortianus* referred to the narcotic liquid named '*Nepenthe*' found in the pitcher plant. The word '*Nepenthe*' is a Greek word which gives a meaning without grief (Phillips et al., 2008). Hence, the '*Nepenthe*' acts as a drug and was given to the wounded soldier during *Homer's The Odyssey* to help relieve their pain (D'Amato, 1998).

The *Nepenthes* L. were distributed in a straddle range from the west at Madagascar and Seychelles, throughout part of Southeast Asia and to the east at New Caledonia in France (Rizqiani et al., 2018). Astonishingly, a huge number of *Nepenthes* species are endemic to the Malesia region (Clarke, 2001a) which Borneo, Sumatra and the Philippines are the richest areas of *Nepenthes* species (Moran & Clarke, 2010). Besides, Clarke et al. (2018a) eloquently stated that there are at least 160 species distributed worldwide. The number of *Nepenthes* species is undoubtedly rapidly increasing as many new species were discovered and described each year. There are about 42 species were discovered in Malaysia occupying parts of Peninsular Malaysia and Borneo Island (Sarawak and Sabah) (Ghazalli et al., 2021). The Sarawak state has 27, Sabah state has 22 species while Peninsular Malaysia has relatively poor *Nepenthes* flora which is 14 species (Damit et al., 2018; Tamizi et al., 2020, Ghazalli et al., 2021; 2022). So far, Nabilah Huda et al. (2023) reported that Sarawak owns the largest number of *Nepenthes* taxa in the country with 33 taxa have been described (27

species; five natural hybrids; one variety). All *Nepenthes* species were categorised as protected plants under Section 31 of the Sarawak Wildlife Protection Ordinance 1998 (Marina et al., 2018). Nowadays, most of the *Nepenthes* species are part of carnivorous plants that are listed as threatened by the International Union for The Conservation of Nature (IUCN) (Jennings & Rohrs, 2011). The population of these species has been gradually decreasing because of the degradation of its habitat for development areas, agriculture and industrial purposes as well as its horticulture value (Marina et al., 2018).

2.3 The History of *Nepenthes* L.

The *Nepenthes* species were remarkably discovered and scientifically described by many botanists in the world since the 17th century. The first-ever *Nepenthes* species described is endemic to Madagascar, a country in East Africa (Figure 2.1). In the year 1658, this species was recorded with the name *Anramitaco* by a French Governor of Madagascar, Etienne de Flacourt and the description of the plant was published in his work, *Histoire de la Grande Isle de Madagascar* (History of the Great Isle Madagascar) (Phillips et al., 2008). As reported by Phillips et al. (2008), Etienne de Flacourt described the *Anramitaco* in French as a plant growing about 3 feet high which bears a seven-inch length of hollow flower or fruit like a vase with a lid at the end of its leaves. In addition, he described that the hollow flower or fruit like a vase can be found in two different colours which are red and yellow (being the biggest) and each one contains a half-glass of water after rain (Phillips et al., 2008). This plant description was considered as weak because Etienne de Flacourt did not realise the leafy nature of the *Anramitaco*'s pitchers and another point is that, he was not a botanist (Phillips et al., 2008). Even so, the *Anramitaco* then was redescribed with accurate details and published under a scientific name as *Nepenthes madagascariensis* in the year 1797 by Poirer (Phillips et al., 2008).



Figure 2.1: *Nepenthes madagascariensis* Poir. (taken from Clarke et al., 2018a)

The second *Nepenthes* species encountered, the Sinhalese pitcher plant was from Sri Lanka (Figure 2.2). This Sri Lankan species was the first *Nepenthes* species to be formally named under the Linnaean System of Taxonomy as *Nepenthes distillatoria* L. by Linnaeus in the year 1737 (Phillips et al., 2008). Long before the name *Nepenthes* was established, *N. distillatoria* L. was first recorded by Thomas Bartholin in the year 1677 as *Miranda herba*, a Latin name which means Marvellous Herb (Phillips et al., 2008). Then, in the year 1680, a local name by Dutch Merchant Jacob Breyn, *Bandura zingalensium* was commonly used for this pitcher plant (Phillips et al., 2008). Phillips et al. (2008) also mentioned that this pitcher plant was finally illustrated concisely and given the name *Planta Mirabilis distillatoria* (Miraculous Distilling Plant) by Swedish Doctor Grimm in the year 1683.



Figure 2.2: Illustration of *Nepenthes distillatoria* L. (taken from Loddiges, 1827)

Afterwards, a common swamp pitcher plant named *Nepenthes mirabilis* (Lour.) Druce from Indonesian islands was described as a third species for the genus *Nepenthes* L. This species was encountered by a German botanist George Everhard Rumph or Rumphius as *Cantherifera* after 10 years the Linnaeus's name *Nepenthes* was published (Phillips et al., 2008). The illustrations and the descriptions of the *Cantherifera* were written in his studies, Herbarium Amboinensis which consisted of six volumes but unfortunately, his full manuscript was not published until the year 1750 because of enormous severe personal tragedy (Phillips et al., 2008). Later in the year 1790, the Portuguese priest Father Joao Loureiro recorded and described a pitcher plant from Vietnam, *Phyllamphora mirabilis* (Marvellous urn-shaped leaf). *Phyllamphora mirabilis* is thought to be the same species as *Cantherifera* (Phillips et al., 2008). Therefore, both of these species were considered a synonym of *N. mirabilis* (Lour.) Druce (Phillips et al., 2008).

2.3.1 The Discovery of *Nepenthes* L. in Borneo

The early discovery of *Nepenthes* in Borneo occurred during the 19th century. Korthals, Low, Veitchii, Burbidge, Curtis, and Hooker were among the earliest botanists who ventured into Borneo, and documented its unique flora, including the *Nepenthes*. The written history of the discovery herein was well documented by Phillips and Lamb (1996), Steiner (2002), and Phillips et al. (2008)

The earliest *Nepenthes* species discovered in Borneo were a Bornean endemic, *Nepenthes boschiana* Korth. and a widespread species, *N. gracilis* Korth. These two species were described by a Dutch botanist, Korthals in the first monograph of *Nepenthes* in year 1839, along with *N. mirabilis* (Lour.) Druce (as *N. phyllamphora* Willd.), *N. rafflesiana* Jack and the other five species from different regions in his treatment; the Sumatran *N. bongso*

Korth, *N. gymnaphora* Reinw. ex Nees from Sumatra and Java, *N. madagascariensis* Poir., and *N. distillatoria* L.

Subsequently, in year 1848, a natural hybrid from Sarawak, *Nepenthes* x *hookeriana* Hort. Veitch ex Mast. was introduced and sent to the nursery, Hugh Low & Co. at Clapton by Hugh Low for flowering. This natural hybrid, a cross between *N. ampullaria* Jack and *N. rafflesiana* Jack was considered merely for a long time as a variety of *N. rafflesiana* Jack. However, Lindley (1848) thought it as a species and then, described it as *Nepenthes hookeriana* in The Gardener's Chronicles. In year 1908, Macfarlane suggested that this species was a hybrid and later, he redescribed and named it as *N* x *hookeriana* after Sir William Hooker, a former Director of the Royal Botanic Gardens, Kew from 1841 until 1865. This interpretation was followed by Danser in his taxonomy treatment of *Nepenthes*.

Hugh Low also discovered the four spectacular *Nepenthes*, named as Kinabalu pitcher plants during his first expedition and following trips with Spenser St. John to the highest mountain in Borneo, Mount Kinabalu in North Borneo (Sabah) in year 1851 and 1858. He sent home the dried specimens of these four *Nepenthes* to the nursery at Clapton and attempted to introduce it, but his effort was failed as their main speciality and focus at the nursery that time was orchids. Nevertheless, these four Kinabalu pitcher plants were later described by Sir Joseph Hooker as *Nepenthes villosa* Hook. f. (1852), *N. lowii* Hook. f. (1859), *N. edwardsiana* Hook. f. (1859), and *N. rajah* Hook. f. (1859). Interestingly, Spenser St. John included the original descriptions of the spectacular four *Nepenthes* by Hooker and the watercolour paintings in his book, Life in the Forests of the Far East in year 1858. Later in year 1873, Hooker published the second monograph on *Nepenthes* named as De Candolle's *Prodromus* and recognised 33 species in it.

Sir Joseph Hooker also described a very unusual pitcher plant, known as *Nepenthes bicalcarata* Hook. f. in *De Candolle's Prodrumus* in year 1873, from specimens collected by Low, and by Beccari. The name *bicalcarata* was given as referring to its unique and distinctive sabre-tooth-like fangs that are projecting down into the pitcher from the lid base. Frederick Burbidge, started to introduce this species to Europe in year 1879, after he made a trip to Kinabalu in year 1877 to collect these plants. These plants then, were cultivated and distributed by the Veitch nursery.

A year after the introduction of the natural hybrid, *N. x hookeriana* Hort. Veitch ex Mast. by Hugh Low, Thomas Lobb, the plant collector shipped a collection of *Nepenthes* to the Veitch nursery, Messrs James Veitch and Sons of the Royal Exotic Nurseries in Chelsea. Thomas Lobb discovered and collected these fine *Nepenthes* species from unknown locations in Borneo which included *N. ampullaria* Jack, *N. rafflesiana* Jack, and two new species, *N. albomarginata* T. Lobb ex Lindl. (Lindley, 1849), with wonderful distinct white ring below its peristome, as well as *N. veitchii* Hook. f. (Hooker, 1859), with the spectacular flared peristome.

In year 1883, Charles Curtis, a collector from the Veitch nurseries sent home the seed of two species that were reportedly from Borneo; *Nepenthes curtisii* Mast., and *N. stenophylla* Mast. These two *Nepenthes* species were then, cultivated in the nursery, and described as *N. curtisii* Mast. in year 1887, and *N. stenophylla* Mast. in year 1890 by Masters. However, there were disagreements among the botanist about the status of these two species. There were speculations about the origin and the identity of *Nepenthes curtisii* Mast., so, this species has been described as a synonym of *Nepenthes maxima* Reinw. ex Nees. Also, many taxonomists doubted the type specimen of *Nepenthes stenophylla* Mast. collected by Charles Curtis and described by Masters, was not the actual specimen that represents this species.

This doubts and arguments are fully discussed by several authors such as Clarke (1997), Jebb and Cheek (1997), and Cheek and Jebb (2001).

Charles Curtis also brought home the finest species from Sarawak, Borneo, *Nepenthes northiana* Hook. f. to be cultivated in the Veitch nursery in year 1883. *Nepenthes northiana* Hook. f. was firstly discovered by an artist, Marianne North at the limestone mountains, during her travels and stayed in Kuching, Sarawak with Charles Brooke, and his wife, Margaret. She painted this spectacular pitcher plant (Figure 2.3) and showed it to Sir Harry Veitch, who recognised it as an undescribed species. In year 1881, Sir Joseph Hooker formally described this pitcher plant and named it as *Nepenthes northiana* Hook. f. after the name of Marianne North. The original painting of this species was donated by Marianne North to Kew Gardens, and preserved in the Marianne North Gallery (Figure 2.4) that was designed by herself to display all her priceless collection of her own painting of variety plants during her travels around the world.

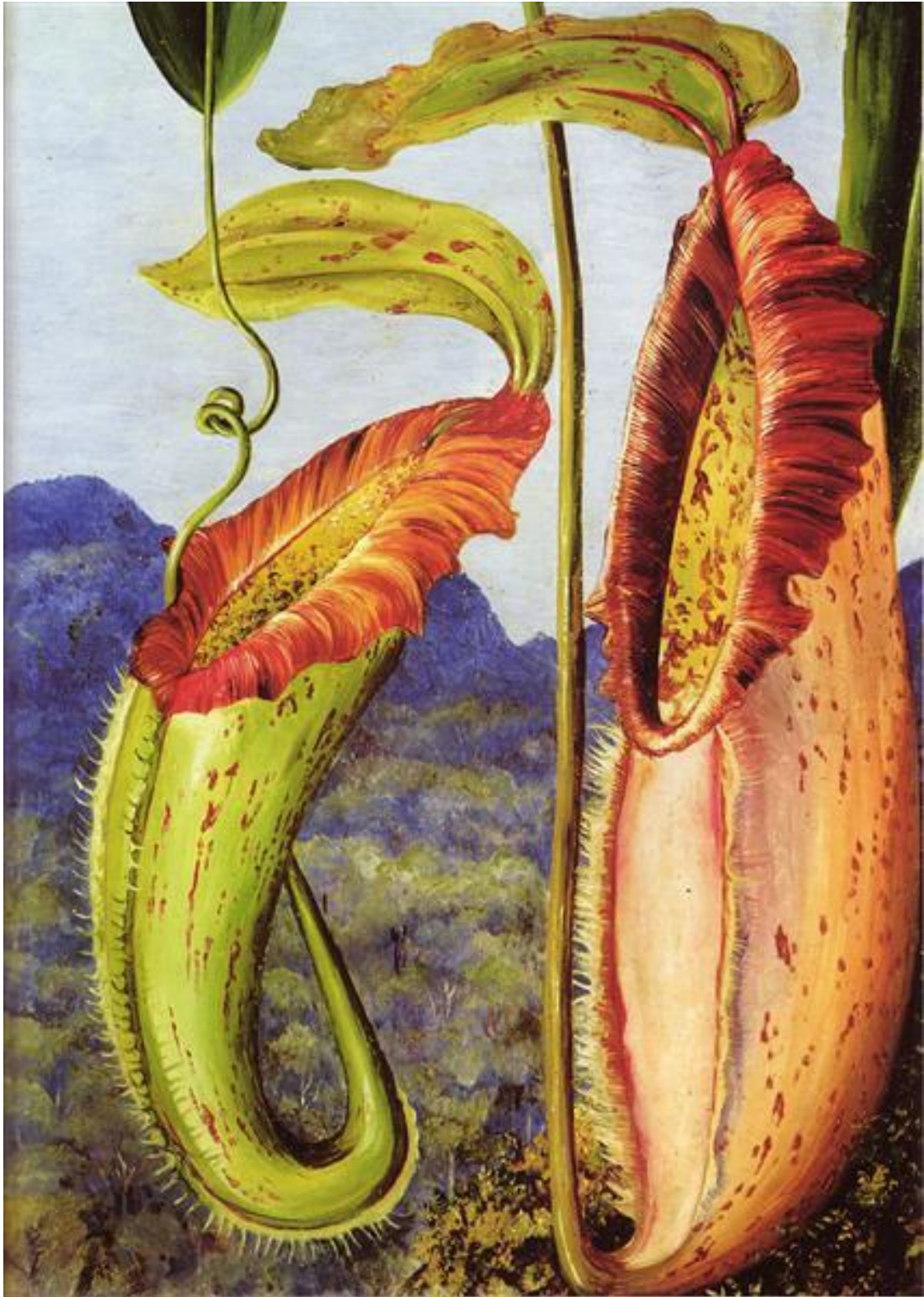


Figure 2.3: A painting of *Nepenthes northiana* Hook. f. by botanical artist, Marianne North, from the limestone hills of Bau, Kuching, Sarawak (Phillips et al., 2008)



Figure 2.4: Beautiful paintings by botanical artist, Marianne North are displayed in the Marianne North Gallery at Kew Gardens

2.3.2 The Discovery of *Nepenthes* L. in Sarawak, Borneo

The discovery of variety spectacular *Nepenthes* species in Sarawak in the early years since the 19th century has attracted many other botanists and taxonomists to continue working on this genus especially in Sarawak. Since then, many new species were discovered throughout the state, and this has contributed to the rising number of the *Nepenthes* species in Sarawak. A natural hybrid, *N. x hookeriana* Hort. Veitch ex Mast was the first Borneo *Nepenthes* to be introduced from Sarawak, and had ignited the enthusiasm of the horticulturalists of Britain (Phillips et al., 2008). Also, *Nepenthes northiana* Hook. f. (Hooker, 1873), the most noteworthy and well-known pitcher plant was introduced in the early years of the discovery of *Nepenthes* in Borneo as an endemic limestone species from Bau, and Padawan areas at Kuching, Sarawak. Other *Nepenthes* taxa that were discovered initially at Sarawak, are listed in the Table 2.2, according to their respective years of publication.

Table 2.2: List of new *Nepenthes* taxa firstly discovered at Sarawak, Borneo

Publication year	Name of <i>Nepenthes</i> species/taxon	Type Localities	Collectors and collection years
1848	<i>N. x hookeriana</i> Hort. Veitch ex Mast	Not Located	Hugh Low (1847)
1873	<i>N. bicalcarata</i> Hook. f.	Lawas River	Hugh Low and Beccari (no date)
1873	<i>N. hirsuta</i> Hook. f.	Lawas River	Hugh Low (no date)
1873	<i>N. tentaculata</i> Hook. f.	Not Located	Thomas Lobb (1853)
1881	<i>N. northiana</i> Hook. f.	Jambusan	Charles Curtis (no date)
1895	<i>N. hispida</i> Beck	Lawas River	Hugh Low or Frederick Burbidge (no date)
1966	<i>N. muluensis</i> Hotta	Mount Mulu	M. Hotta (1964)
1991	<i>N. faizaliana</i> Adam & Wilcock	Mulu National Park	Lai and Jugah (1981)
1992	<i>N. mirabilis</i> var. <i>echinostoma</i> Adam & Wilcock	Kuching	Beccari (no date)
1997	<i>N. murudensis</i> Culham ex Jebb & Cheek	Mulu National Park	Yii Puan Ching (1982)
2001	<i>N. platychila</i> Chien C. Lee	Mount Bukit Batu in Hose Mountains, central Sarawak	Chien C. Lee (2001)
2002	<i>N. vogelii</i> Shuit. & de Vogel	Kelabit Highlands	De Vogel, Schuiteman and Roelfsema (2001-2002)
2003	<i>N. hurrelliana</i> Cheek & Lamb	Borneo (Sabah, Sarawak, and Brunei)	No Data
2004	<i>N. glandulifera</i> Chien C. Lee	Hose Mountains, central Sarawak	Chien C. Lee (2001)

Table 2.2 continued

2004	<i>N. x bauensis</i> Chien C. Lee	Bau, Kuching	Chien C. Lee (1988)
2006	<i>N. chaniana</i> Clarke, Chien Lee & McPherson	Bukit Batu Lawi, Bario	Awa and Chien C. Lee, (1995)
2011	<i>N. appendiculata</i> Chien C. Lee, Bourke, Rembold, Taylor & Yeo.	Hose Mountains	Chien C. Lee (2011)
2020	<i>N. fractiflexa</i> Golos, Robinson & Barer	Mount Mulu National Park	Anderson (1961)

Since Cheek and Lamb (2003) published a new species, *Nepenthes hurrelliana* Cheek & Lamb from Borneo (Sabah, Sarawak, and Brunei), the total number of *Nepenthes* in Borneo was updated to 36 species. This finding has directly contributed to the increasing number of *Nepenthes* species in Sarawak. Moreover, many new locality records of *Nepenthes* species were discovered in Sarawak, such as *Nepenthes campanulata* Kurata, and *N. ehippiata* Dans, as these two species were previously known from Kalimantan, Indonesia only (Lee, 2004). Then, Clarke and Lee (2004a) reported that there were a total of 25 *Nepenthes* species recorded from Sarawak. However, this number is rising to 28 species (Table 2.3) with the addition of new species, *N. appendiculata* Chien C. Lee, Bourke, Rembold, Taylor & Yeo (Lee et al., 2011), and the most recent and latest species, *N. fractiflexa* Golos, Robinson & Barer from Sarawak (Golos et al., 2020). Also, the discovery of the variety and natural hybrids of *Nepenthes* in Sarawak also has added to the recent number of species, which, it is now more than 28 taxa.

Table 2.3: The updated list of *Nepenthes* species in Sarawak

List of <i>Nepenthes</i> species in Sarawak	
1. <i>Nepenthes albomarginata</i>	15. <i>Nepenthes hurrelliana</i>
2. <i>Nepenthes ampullaria</i>	16. <i>Nepenthes lowii</i>
3. <i>Nepenthes appendiculata</i>	17. <i>Nepenthes mirabilis</i>
4. <i>Nepenthes bicalcarata</i>	18. <i>Nepenthes muluensis</i>
5. <i>Nepenthes campanulata</i>	19. <i>Nepenthes murudensis</i>
6. <i>Nepenthes chaniana</i>	20. <i>Nepenthes northiana</i>
7. <i>Nepenthes ehippiata</i>	21. <i>Nepenthes pilosa</i>
8. <i>Nepenthes faizaliana</i>	22. <i>Nepenthes platychila</i>
9. <i>Nepenthes fractiflexa</i>	23. <i>Nepenthes rafflesiana</i>
10. <i>Nepenthes fusca</i>	24. <i>Nepenthes reinwardtiana</i>
11. <i>Nepenthes glandulifera</i>	25. <i>Nepenthes stenophylla</i>
12. <i>Nepenthes gracilis</i>	26. <i>Nepenthes tentaculata</i>
13. <i>Nepenthes hirsuta</i>	27. <i>Nepenthes veitchii</i>
14. <i>Nepenthes hispida</i>	28. <i>Nepenthes vogelii</i>

2.4 Taxonomy of *Nepenthes* L.

2.4.1 Infrageneric Classification of *Nepenthes* L.

The genus *Nepenthes* often grow in remote and inaccessible areas and they have a high degree of endemism where most of the species only grow in particular habitats such as single mountain and cliff-face which lead to a problematic and taxonomically challenging for this genus since the early research, hence, the number of authentic *Nepenthes* species remain unclear (Thorogood, 2010). In 1928, Danser in his monograph, *The Nepenthaceae of the Netherlands Indie* described the genus and classified the species into six sections according to its morphological characteristics and radiations based on a Gondwanan hypothesis. This initial taxonomy grouping of the *Nepenthes* species was of fundamental importance for taxonomic studies in the genus and yet, no new infrageneric classification has been proposed to replace the Danser's groups (Cheek & Jebb, 2001; Thorogood, 2010). Those six sections are section *Insignes*, *Montanae*, *Nobiles*, *Regiae*, *Urceolatae* and *Vulgatae*. Notwithstanding, Danser (1928) did acknowledge that his infrageneric classification did not reflect the evolutionary relationship between the *Nepenthes* species.

The first section is *Vulgatae* which included *Nepenthes* species with 'simple' morphological features such as glabrous stems, small leaves and pitchers with inconspicuous peristomes (Thorogood, 2010) and it was elucidated more by Cheek and Jebb (2001) that they have fine climbing stems with 2/5 leaves arrangement, leaves mostly lanceolate, usually small and narrow; peristome narrow, pitchers small, rarely infundibuliform; inflorescence racemose or paniculate and indumentum usually fine, not red-brown or absent. There are *ca.* 12 *Nepenthes* species as reported by Cheek and Jebb (2001) that are widely distributed in the Malay Archipelago and some of them are from the western region such as *N.*

albomarginata Lobb, *N. gracilis* Korth, *N. mirabilis* (Lour.) Druce, *N. reinwardtiana* (Miq.), and *N. tentaculata* Hook. f. (Thorogood, 2010).

The next section is *Urceolatae* which consisted of only two true species, *N. ampullaria* Jack and *N. bicalcarata* Hook. f., and this group was restricted to the Sunda-Shelf region, Borneo and New Guinea (Thorogood, 2010). Both species were assigned to this group as they portrayed the lower pitchers with an urceolate shape and broadly ovate with an inner surface that is entirely glandular while the upper pitchers can be found funnel-shaped (Cheek & Jebb, 2001; Thorogood, 2010). Danser (1928) also described a section named *Insignes* which occurred primarily in Borneo and New Guinea. The members of this section are *Nepenthes* species with leaves that are large, sessile and petiolate, pitcher large, campanulate-infundibuliform with its peristome flattened or expanded and the indumentum usually fine or absent (Cheek & Jebb, 2001; Thorogood, 2010). Meanwhile, the section *Nobiles* was reported by Thorogood (2010) as a poorly defined group as it comprised *Nepenthes* species with intermediate morphological characteristics between the *Vulgatae* and *Montanae* to *Regiae*, and included *Nepenthes hirsuta* Hook. f.

Montanae, another section introduced by Danser (1928) which included species that are endemic to Peninsular Malaysia such as *N. sanguinea* Lindl., *N. macfarlanei* Hemsl. and *N. gracillima* Ridl. and also species that occurred in Sumatra, Java and Borneo. The members of this section can be recognised easily by their robust and sessile leaves with larger pitchers in funnel-shaped and broader peristomes. Last but not least, section *Regiae*. This section was well-known with very large species that are widely distributed in the Malesia region but restricted only to Borneo but extended to New Guinea (Thorogood, 2010). Cheek and Jebb (2001) specifically stated that there are 15 species under this section which are *N. veitchii* Hook. f., *N. stenophylla* Mast., *N. fusca* Danser, *N. maxima* Reinw. ex Nees., *N. lowii* Hook.

f., *N. rajah* Hook. *f.* and *N. burbridgeae* Hook. *f. ex* Burb. Generally, as described by Cheek and Jebb (2001), these species have coarse stems showing $\frac{1}{2}$ phyllotaxy when climbing, petiolate leaves with large infundibuliform or funnel-shaped pitchers and expanded or flattened peristomes.

Nevertheless, Cheek and Jebb (2015, 2016a, 2016b, 2016c) revised the entire genus and added five new infrageneric sections, *Alatae*, *Micramphorae*, *Pyrophytae*, *Tetaculatae* and *Villosae* with a new subsection named *Poculae-ovis* and informal *Danseri* group. But, only three of the newly described sections (*Pyrophytae*, *Tentaculatae* and *Villosae*) were recognised by Clarke (2018a) and he dropped the group *Nobiles* from Danser's infrageneric classification of *Nepenthes* as it was lectotypified by Cheek and Jebb (2015, 2019). The section *Montanae* and *Regiae* persist in a large group despite their different interpretations (Murphy et al., 2020) but the section *Montanae* has been limited by Clarke et al. (2018a) to Sumatra and Java only as all the taxa from Peninsular Malaysia and Indochina was reassigned in an extended section *Pyrophytae*. Besides, Clarke et al. (2018a) also rearranged the Philippine (mainly Mindanao) taxa from the large section *Alatae* to the sections *Regiae* and *Villosae*. Apart from this, Clarke et al. (2018a) revised three *Nepenthes* species which are *N. gracilis* Korth, *N. mirabilis* (Lour.) Druce and *N. papuana* Danser to the small group, *Urceolatae* along with the *N. ampullaria* Jack and *N. bicalcarata* Hook. *f.* and not only that, he renamed the group *Vulgatae* by Danser (1928) as section *Nepenthes* on the nomenclatural ground.

2.4.2 Hybridisation and Habitat Specificity in Genus *Nepenthes* L.

Hybridisation among the *Nepenthes* species is extensive either natural or man-made and it is one of the main drivers in the speciation of the genus *Nepenthes* (Thorogood, 2010). Several factors may influence the process of interbreeding which involved the pattern of the

sexuality of the *Nepenthes* species as all of them are dioecious, hence, it has allowed them to obligately out-crossing and freely cross-compatible between the *Nepenthes* species (Thorogood, 2010). Moreover, many *Nepenthes* species are sympatric and their seeds are wind-dispersed which can cause them occasionally produce hybrids (Thorogood, 2010). Jeeb and Cheek (1997) reported that there are over 280 hybrids names were published and 193 of which involved more than two parents. Also, it was no doubt that the number of natural and cultivated hybrid species of *Nepenthes* is increasing nowadays.

Habitat specificity also was found to as a main driver of speciation in the genus *Nepenthes*. Thorogood (2010) mentioned that some species are very specialist in their habitat preferences, for instance, *N. rajah* Hook. f., *N. burbridgeae* Hook. f. ex Burb., and *N. villosa* Hook. f. which are restricted to ultramafic substrates in the Kinabalu Park area only while *N. northiana* Hook. f. grows exclusively on limestone rocks in Sarawak. Nevertheless, they have their particular altitudinal preferences despite occurring on the same substrates which then results in growing different niches area (Thorogood, 2010). Additionally, several lowland species including *N. gracilis* Korth, *N. mirabilis* (Lour.) Druce, and *N. rafflesiana* Jack often prefer to grow in disturbed environments and secondary vegetation (Thorogood, 2010). However, the habitat preferences of *N. mirabilis* (Lour.) Druce and *N. maxima* Reinw. ex Nees are different as both of them have a wide range of habitats and they show a high level of intraspecific variability. Meanwhile, the *N. veitchii* Hook. f. form ecotypes that are adapted to particular habitats (Thorogood, 2010). These situations may contribute to habitat-driven divergence and speciation in the genus *Nepenthes* L.

2.5 General Morphology of *Nepenthes* L.

Small numbers of *Nepenthes* can be found growing epiphytically on the tree while the others are mostly climbers and scramblers in terrestrial habitats (Clarke, 2001a; Marina et al., 2018). This carnivorous plant can be notable easily by its unique morphological characteristics which are manifested by its pitchers, leaves and inflorescences. Naturally, pitcher plants can be found in two different forms which are upper or aerial pitcher plants and lower or terrestrial pitcher plants despite they are the same species.

2.5.1 The Leaves of *Nepenthes* L.

According to Clarke (2001a), the leaves of *Nepenthes* can grow in a rosette form or a climbing stem. Generally, the leaves can be found in lanceolate or spatulate shape with a long tendril (extension of the midrib) protruding from the apex of its leaf. The leaf morphology of *Nepenthes* species was further illustrated by Thorogood (2010) in Figure 2.5. The tendrils are normally straight (uncoiled) on rosette leaves, meanwhile, those of the climbing stems have a loop (coiled) halfway between the apex of the leaf and the pitcher. The loop of tendrils usually will encircle the near objects to get support for the stem when they bear a heavy fluid-filled pitcher (Clarke, 2001a). He added further that the venation of the lamina is unique; its veins usually are a combination of longitudinal and branching and described that venation is distinctive in some species.

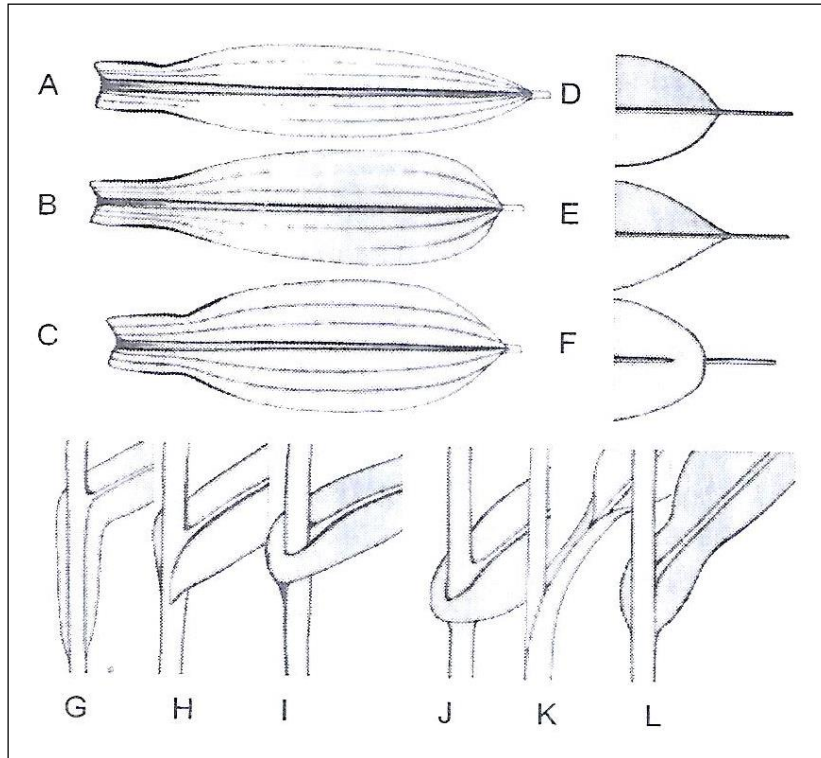


Figure 2.5: Leaf morphology of *Nepenthes* L. adopted from Thorogood (2010); A. lanceolate leaf blade; B. spathulate leaf blade; C. obovate leaf blade; D. acutely-tapered apex; E. gradually-tapered apex; F. peltate apex; G. decurrent at the base; H. Semi-clasping at the base; I. wholly clasping at the base; J. apetiolate; K. narrowly petiolate; L. broadly petiolate

2.5.2 The Pitchers

The *Nepenthes* species can be differentiated easily through its spectacular pitchers that portrayed various unique characteristics in terms of their colouration, shape and size of the pitcher, fringes and wings and many more. Nonetheless, they still possess and share a few basic characteristics which consisted of four main parts (Figure 2.6) which are the main pitcher cup, the peristome, the lid and a pair of fringed wings that run down the front of the pitcher (Clarke, 2001a; Clarke & Lee, 2004). Each leaf (the true lamina) of the plant will only bear one pitcher (the modified leaf) that is capable to trap and digest the prey mainly insects for nutrient absorption (Clarke & Lee, 2004). Despite that, Clarke and Lee (2004)

stated that not all leaves will successfully develop pitcher buds as it depends on different environmental factors such as humidity, light levels, damage by insects and many more and also, the plant will fail to produce the pitchers when the humidity and light levels are too low and the nutrient availability in the growth area is too high.

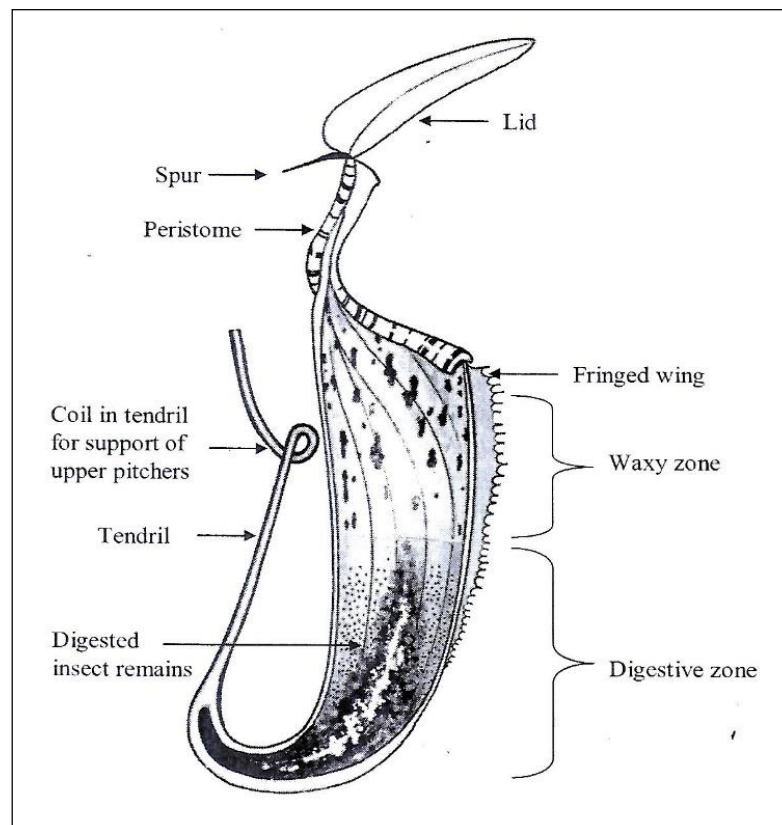


Figure 2.6: Gross anatomy of *Nepenthes* pitcher (taken from Thorogood, 2010)

2.5.3 The Inflorescences

Nepenthes are dioecious which means their male and female reproductive organs are developed in the separated individual of the plant. Phillips et al. (2008) described that the cylindrical inflorescences are formed erect in a raceme or racemose or panicle at the terminal of the *Nepenthes* plant while bearing numerous flowers with four undifferentiated petal-like-tepals on the pedicels. There are one to two or three and can be found occasionally more

flowers are produced on each pedicel (Phillips et al., 2008) and they are open acropetally in the inflorescence (Cheek & Jebb, 2001). The flowers have an odour that is often scented as a slightly musky or fungus-like, sweet scent or has no scent at all (Cheek & Jebb, 2001).

Interestingly, the *Nepenthes* flowers carried sessile glands secreting nectar on the adaxial of the tepal with the purpose to attract insect visitors mainly the Hymenoptera and Diptera flies which act as agents of pollination (Cheek & Jebb, 2001). Moreover, the female flowers generally have shorter spikes and narrower tepals compared to the male flowers and they bear capsule fruits which contained hundreds of tiny hair or filament-like seeds in white colour (Phillips et al., 2008). Meanwhile, the male flowers of *Nepenthes* developed filaments with yellow anther heads producing a mass of pollen grains that are dispersed by wind (Cheek & Jebb, 2001). Each *Nepenthes* species can produce inflorescences with a different number of flowers as some of them can bear up to 700 flowers, with 0-6 flowers opening per day, for instance, *N. rajah* Hook. f., *N. villosa* Hook. f. and *N. x kinabaluensis* Sh. Kurata ex Sh. Kurata as reported by Adam (1998). Cheek and Jebb (2001) mentioned that the number of flowers on the flower stalk can be a very useful taxonomic character in delimiting the taxa in the genus *Nepenthes*.

2.6 Anatomical Study of *Nepenthes* L.

Plant anatomy is one of the branches in botany that focuses on plant cell tissues and cell structures. Few anatomical characteristics have been identified and listed by Radford (1986) as valuable taxonomic and systematic evidence; stomata, trichomes, type of vascular bundles, rays, ground tissue and parenchyma, epidermal and mesophyll tissue, sclereids, nodes, phloem cell, type, size, shape, wall sculpture and pattern of wood cells, and many more. In the genus *Nepenthes* L., the systematic identification of the species was mainly based on the pitcher's morphology (Ridley, 1924; Corner, 1988). Without the presence of

the pitchers, species identification and differentiation are confusing and taxonomically challenging. Therefore, it is crucial to investigate other characteristics such as the anatomy of the *Nepenthes* L. as an alternative to providing useful information in delineating the species.

Several anatomical studies have been conducted specifically on the leaf epidermal anatomy and midrib anatomical characteristics in *Nepenthes* L. Metcalfe and Chalk (1950) conducted the first anatomical study in *Nepenthes* L., using the slides collection preserved at Kew Botanic Gardens. Later, this study has been continued by other researchers using cultivated *Nepenthes* specimens such as *N. maxima* Reinw. ex Nees (Toma et al., 2002), *N. mirabilis* (Lour.) Druce and *N. alata* Blanco (Pavlovic et al., 2007), *N. gracilis* Korth, *N. rafflesiana* Jack, and *N. x hookeriana* Horth. Veitch ex Mast (Biati, 2012), and *N. gracilis* Korth (Paluvi et al., 2015). Also, more anatomical analyses on a few species have been conducted by Al Farishy et al. (2017), Arimy et al. (2017), yet, there is still a lack of data on the anatomical evaluation of the wild specimen.

Ghazalli et al. (2021) also reported that there are scarce information and knowledge related to the anatomical descriptions of *Nepenthes* species, particularly in Peninsular Malaysia. Thus, ten species from Peninsular Malaysia have been studied anatomically; *N. alba*, *N. albomarginata* T. Lobb ex Lindl., *N. ampullaria* Jack, *N. benstonei* Clarke, *N. gracilis* Korth, *N. macfarlanei* Hemsl., *N. mirabilis* (Lour.) Druce., *N. ramispina* Ridl., *N. sanguineae* Lindl., and *N. rafflesiana* Jack (Ghazalli et al., 2021). This most recent study concentrated on the leaf lamina, stomatal type, margin, petiole, vascular bundle patterns, leaf venation, and appendage variation. In Borneo, especially Sarawak, however, no leaf anatomical study has ever been conducted before.

2.7 Palynological Study of *Nepenthes* L.

The study of pollen is one of the most important scientific disciplines as it can give a significant amount of information from tiny materials which as pollen grains in an instant time (Walker & Doyle, 1975). Heywood (1976) mentioned that the characteristics of the pollen grains and spores including the size and shape, pollen type, number and position of the apertures and pollen wall architecture are progressively used in the systematic studies of the plant. These finest details of the pollen grains can be observed clearly with the aid of Transmission Electron Microscopy (TEM) and Scanning Electron Microscopy (SEM) instead of using the light microscope (Adam & Wilcock, 1999). Past research had proved that the palynological data are very useful in solving the taxonomic problem such as delimiting plant taxa in Umbelliferae (Cerceanu-Larrival, 1971) and Compositae (Skvarla & Turner, 1966) based on the pollen morphological characteristics. Furthermore, the pollen study also helped Jeffrey (1964) in establishing a new system of classification in the family Curcubitaceae.

In the genus *Nepenthes*, scarce research in palynological studies related to taxonomic work had been carried out. So, Adam and Wilcock (1999) conducted the first research on pollen grains from 27 Bornean *Nepenthes* to figure out the variety of pollen morphological characteristics within and between the species and also to find out whether these data can be useful in differentiating the species and section in genus *Nepenthes*. Adam and Wilcock (1999) concluded that the pollen morphology data are not useful in the taxonomic work in the genus *Nepenthes* either at the specific level or sectional as the pollen characters (Aperture type, exine sculpturing, pollen unit and shape) are homogenous among the Bornean *Nepenthes*. Yet, Adam and Wilcock (1999) classified the 27 Bornean *Nepenthes* species into

three groups (Group I, Group II and Group III) as in Table 2.4 based on their mean pollen tetrads diameter.

Table 2.4: Summarisation of pollen groups for 27 Bornean *Nepenthes* species with their pollen tetrad means diameter derived by Adam and Wilcock, 1999

Pollen Group	Mean diameter of pollen tetrad	Scientific Name	Section Name	Altitude (m)
Group I	27 µm	<i>N. gracilis</i>	Vulgatae	30-80
Group II	28.5 µm to 34.7 µm	<i>N. ampullaria</i>	Urceolatae	10-200
		<i>N. bicalcarata</i>	Urceolatae	-
		<i>N. mapuluensis</i>	Regiae	800
		<i>N. hirsuta</i>	Nobiles	-
		<i>N. curtisii</i>	Regiae	1000-1400
		<i>N. northiana</i>	Insignes	30
		<i>N. tentaculata</i>	Vulgatae	1700
		<i>N. rafflesiana</i>	Insignes	0-60
		<i>N. mirabilis</i>	Vulgatae	-
		<i>N. albomarginata</i>	Vulgatae	0-30
		<i>N. muluensis</i>	Vulgatae	-
		<i>N. hookeriana</i>	Urceolatae	150
Group II	28.5 µm to 34.7 µm	<i>N. faizaliana</i>	Regiae	-
		<i>N. veitch</i>	Regiae	-
		<i>N. lowii</i>	Regiae	1700-2000
		<i>N. reindwartiana</i>	Vulgatae	520-1400
		<i>N. x alisaputraiana</i>	Hybrid	1900
		<i>N. macrovulgaris</i>	Nobiles	520
		<i>N. clipeata</i>	Regiae	-
		<i>N. edwarsiana</i>	Insignes	2600
		<i>N. fusca</i>	Regiae	1500
		<i>N. rajah</i>	Regiae	1930-2320
Group III	37.2 µm to 38.9 µm	<i>N. mollis</i>	Regiae	1800
		<i>N. villosa</i>	Insignes	1800-3400
		<i>N. ehippiata</i>	Regiae	2000
		<i>N. kinabaluensis</i>	Regiae	2800

Following that, Sadhan et al. (2014) attempted to study the pollen morphology of *N. khasiana* Hook. f., an endemic species to Meghalaya, India and compared it with pollen grains data by Adam and Wilcock (1999). The study showed that the aperture type, exine sculpture and tetrad type of *N. khasiana* Hook. f. with the Bornean *Nepenthes* species are similar as well but different in size of the tetrad (Sadhan et al., 2014). The pollen size tetrad of *N. khasiana* Hook. f. is closer to *N. rafflesiana* Jack and *N. mirabilis* (Lour.) Druce in Group II. Hence, they indicated that pollen characteristics such as the size of a tetrad, the length of spines and the thickness of exine could be useful in discriminating the *Nepenthes* species.

According to Stanley and Linskens (1974), there are several external factors and sources that could affect the variation in the size of pollen grains which include mineral conditions, water conditions, temperature as well as internal factors such as chromosome number and flower character. One of the examples is Kiew (1984) where she found out that the size of pollen grains in heterostylous Malesian Oleacea was correlated with the style length.

2.8 The Distribution of *Nepenthes* L.

The main habitats of *Nepenthes* species are mainly located in the tropical territories of the former Gondwanaland, where most of them can be found in mountainous regions which include the Sunda shelf territories (the Greater Sunda Islands with Sumatra, Java, Peninsular Malaysia, Borneo, Sulawesi and the Lesser Sunda Islands), New Guinea, Mollucas, Philippines, Thailand, Vietnam and other countries of Indo-China and some other places (Steiner, 2002). According to Adam et al. (1991), the *Nepenthes* can be categorised into two groups which are the lowland group and the highland group according to their altitude. There are 68% of the plants are grown beyond 1000 m above sea level while the

remaining 32% of them can be found under 1000 m sea level (Kurata, 1976; Steiner, 2002). However, only a few *Nepenthes* species are intermediate which they grow for the lowlands up to a height of 2400 m (Steiner, 2002).

Adam et al. (1991) also explained that the lowland species can be encountered growing in open habitats such as secondary bushes associated with *Gleichenia* (fern), roadside embankments, edges of the forest, swampy areas, heath forest, peat swamp forest and also gaps in lowland dipterocarp forest. Whilst the highland species can be encountered conspicuously in the montane rain forest but are very rare in the submontane rain forest or oak forest. Even though the *Nepenthes* widely occur in different types of vegetation, they are not uniformly distributed throughout any of them as they are likely to have accumulated distributions in open, moist, sunny sites, often along vegetation boundaries (Clarke, 2001a).

2.9 The Interactions Between *Nepenthes* L. and Animals

Nepenthes has great interactions with the animals in terms of capture of prey and digestion for their nutrient acquisition strategies as well as providing, food sources and habitats to some animals. The majority of the trapped prey are arthropods which include insects such as bees, moths and flies, beetles, bugs and also flightless prey (Thorogood, 2010). However, they are not only capable to trap small prey but some *Nepenthes* species such as *N. rajah* Hook. f. which impressively can trap huge prey such as rats on very rare occasions (Clarke, 2001b). Moreover, Greenwood et al. (2011) elucidated that the three giant montane *Nepenthes* species from Borneo, *N. lowii* Hook. f., *N. rajah* Hook. f. and *N. macrophylla* (Marabini) Jebb & Cheek are engaged very well in an incredible mutualistic association with the treeshrews known as *Tupaia montana* Thomas, and *Rattus baluensis* Thomas. These treeshrews will defecate into the *Nepenthes* pitcher while licking the carbohydrate-rich nectar secreted by the glands under the pitcher lid in their visit and the

faeces then will give nutrients to the pitcher plant (Figure 2.7) (Clarke et al., 2009; Chin et al., 2010; Greenwood et al., 2011).

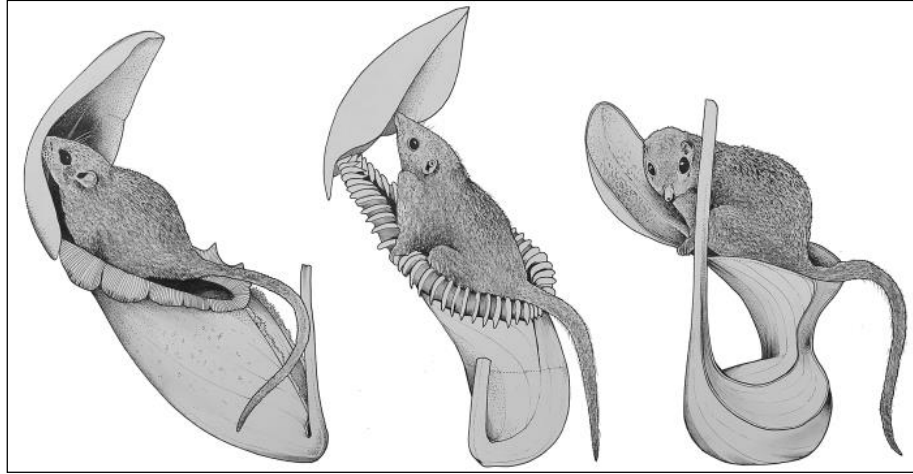


Figure 2.7: The treeshrews are defecating into pitchers of the three giant montane *Nepenthes* species while licking the nectar secreted by the glands developed under the pitcher lid (taken from Thorogood, 2010)

CHAPTER 3

MATERIALS AND METHODS

3.1 Sample Collection and Field Observations

Eighteen taxa of *Nepenthes* were included in the study; 13 species, one variety, and four natural hybrids. Among them, five taxa were recorded based on the herbarium specimens deposited in SAR and the rest were collected from the field. The study sites involved the western area of Sarawak which consisted of four divisions, Kuching, Samarahan, Serian, and Sri Aman (Figure 3.1 and Figure 3.2). The *Nepenthes* plant samples were collected in several areas including the Totally Protected Area (TPA), forest reserves, undisturbed forest, and, disturbed areas/forests such as roadside embankment areas, and open areas. The research done in the Totally Protected Areas such as Bako National Park, Santubong National Park, Kubah National Park, Gading National Park and others were allowed with a permit approved by Sarawak Forestry Corporation (**Appendix D**).

A variety of *Nepenthes* taxa was collected at different altitudes of lowland areas, below 1000 m above sea level throughout the study period. At least three plant samples were collected for each *Nepenthes* taxa to be further analysed in the laboratory at the Faculty of Resource Science and Technology, Universiti Malaysia Sarawak. The localities and the coordinates of each collected plant were recorded for distribution reference. Also, general morphological characteristics and several parameters of ecology such as the type of forest/habitat, elevation distribution, pH and moisture of soil were observed in the field and recorded as well.



Figure 3.1: Location of Sarawak state in the map of Malaysia (taken from Nations Online, n.d.)



Figure 3.2: Map of Sarawak, Borneo, Malaysia

3.1.1 Distribution

The distribution of the *Nepenthes* taxa studied were analysed based on the GPS (Geographic Coordinate System) coordinates recorded at the field and location data from the SAR herbarium specimens. Each GPS coordinate of the locations in latitude and longitude for each *Nepenthes* taxa studied were converted into decimal formats. Then, these points were used to generate a distribution map of *Nepenthes* taxa in western Sarawak using an open source software, QGIS 3.34.1.

3.1.2 Habitat and Ecology

The reading of the soil pH and moisture of each *Nepenthes* habitat were measured during sample collection activities at the study sites by using Takemura DM-15 Soil pH and Moisture Tester. The soil pH can be categorised into three classifications according to their pH values; acidic (<7.0), neutral (7.0), and alkaline (>7.0). Meanwhile, the soil moisture in the value range of $1.0 - 8.0\%$ were considered as wet soil, and if the value is below the minimum range, it was considered as dry soil. The reading of the soil pH was expressed in pH unit while, the soil moisture was in percentage (%) unit.

The soil pH and moisture tester was inserted directly into the soil of the *Nepenthes* habitat until the metallic surface and tamp completely embed down the surrounding soil to make sure it adheres closely to the meter's metallic electrode surface. After one minute, the reading of the soil pH was taken after the pointer was ceased to deflect the actual value. For the soil moisture, the white button of the tester was pressed to gain the reading. The readings of both parameters were taken at least at three different points of the soil of the *Nepenthes* habitat to get an average value.

3.2 Preparation and Preservation of Herbarium Samples

The herbarium specimens of the *Nepenthes* studied were prepared based on the standard herbarium method described by Bridson and Forman (1992). All the collected *Nepenthes* fresh samples were flattened and pressed in the old newspaper and stacked alternately with the other samples along with the corrugated zinc sheets properly before they were tied up with the zinc frame and buckle straps. Then, they were dried in the oven within seven to eight days at 60°C. After the drying process was completed, the dried samples were mounted on the mounting board by using PVA glue and stitched with a thread to secure them. All the important characteristics of the *Nepenthes* plants such as the leaves, pitchers, inflorescence or the infructescence, and others were included in the identification process. Moreover, each herbarium sample of *Nepenthes* plants was accompanied by labels containing information, for instance, the scientific name, collector's name, locality or location, coordinates and altitudes, habit and habitat with their general morphological descriptions. Not only that, the male and female inflorescences or infructescence were preserved in the 70% alcohol. All herbarium specimens of the *Nepenthes* taxa studied, then were deposited into Sarawak Herbarium (SAR) at Kuching, Sarawak.

3.3 Morphological Study

The morphological characteristics of the fresh samples and/or herbarium specimens of each *Nepenthes* studied were observed and described briefly based on their field characteristics and cross-references to literature and dichotomous key elucidated by Cheek and Jebb (1997), Clarke et al. (1997), Cheek and Jebb (2001), and Thorogood (2010). The describing process of each *Nepenthes* plant structure involved various parameters such as the shape, the measurements, the colours and the texture (Table 3.1).

Table 3.1: The structures and parameters of *Nepenthes* morphological descriptions based on Cheek and Jebb (1997), Clarke et al. (1997), Cheek and Jebb (2001), and Thorogood (2010)

Structure of <i>Nepenthes</i> plant	Parameters
Habits	Type of habit, height of plant, type of pitcher (upper or lower pitcher plant).
Stem	Shape of the stem, diameter of the stem, length of internode.
Leaves	Length and width of the leaves, shape of blade, apex shape, base shape, the texture of leaves, petiolate or sessile, length of petioles, leaf attachment, type of margin, type of leaf veins, number of leaf veins.
Tendrils	Length of tendril, coiled or uncoiled,
Pitcher	Upper or lower pitcher plant, shape of the pitcher, height of the pitcher, width of the pitcher; presence or absence of fringe wings, length of fringe element, distance between two fringe elements; shape of pitcher mouth, width of mouth; shape of peristome, width of peristome, presence or absence of teeth with its measurement; shape of lid, length and width of the lid, apex shape, base shape, presence or absence of appendages, type or shape of gland, size of the gland.
Male Inflorescence	Type of inflorescence, length of the inflorescence rachis, length of the peduncle, diameter of the rachis and peduncle, shape of peduncle, texture of peduncle, number of flowers, length of pedicel, shape of tepal, length and width of tepal, apex shape, base shape, length of androphore, width of anther head.
Female Inflorescence/Infructescence	Type of inflorescence, length of the inflorescence rachis, length of the peduncle, diameter of the rachis and peduncle, shape of peduncle, texture of peduncle, number of flowers, shape of fruit, length of fruit, type of seeds, length of seeds.
Indumentum	Type of indumentum, length of hairs.
Colour	The colour of each structure were describe briefly according to the colour chart provided by Beentje (2010).

3.4 Micromorphological Study

Thirteen collected *Nepenthes* taxa were included in the micromorphological study. The taxa are *N. albomarginata*, *N. ampullaria*, *N. gracilis*, *N. hirsuta*, *N. hispida*, *N. mirabilis*, *N. mirabilis* var. *echinostoma*, *N. nazreeana* sp. nov. ined., *N. rafflesiana*, *N. reinwardtiana*, *N. x hookeriana*, *N. x kuchingensis*, and *N. x trichocarpa*. The micromorphology of the *Nepenthes* taxa, including the indumentum or trichome, glands, stomata and others were observed under Field Emission Scanning Electron Microscopy (FESEM). There were at least four samples of each *Nepenthes* studied and three replicates were prepared for the observations under FESEM (Table 3.2). The samples were prepared in several steps before the FESEM observation, including dehydration with various percentages of ethanol, C₂H₆O, Critical Point Drying (CPD), mounting on stubs, and fine coating. The preparation of the samples for FESEM were processed using modified procedures, as outlined by several authors such as Halbritter (1997), and Echlin (2009).

Table 3.2: Selected structures of 13 *Nepenthes* studied observed under the FESEM

No.	Structures
1.	Adaxial surface of leaves.
2.	Abaxial surface of leaves.
3.	Adaxial surface of the upper part of the pitcher body.
4.	Adaxial surface of the lower part of the pitcher body.

3.4.1 Dehydration of Samples

The selected structures from the *Nepenthes* studied were cut off using a scalpel into portions with measurements about 0.5 cm x 0.5 cm. Then, they were fixed and preserved in the 7 ml Mc Cartney Bijou bottle containing 4% Glutaraldehyde fixative for at least two hours in the refrigerator at 4°C before use. However, due to the limited resources of

Glutaraldehyde, Formalin-Acetic-Alcohol (FAA) solution or 70% ethanol was used as another alternative to preserve and fixed the samples and then followed with the dehydration process in the series of ethanol concentrations.

Each fixed sample was washed in the 0.1 M Phosphate Buffer solution at pH 7.2. The preparation of the samples then was continued with the dehydration process using a series of percentages of absolute Ethanol, 50%, 60%, 70%, 80%, 90%, and 100% to minimise the shrinkage and distortion of the samples. The fixed samples were initially dehydrated in 50% Ethanol for 15 minutes and followed with 70% Ethanol for 15 minutes as well. Subsequently, the dehydration process continued by immersing the samples in the 90% Ethanol two times for 15 minutes each and eventually fully removing the water from the samples in the 100% Ethanol three times for 20 minutes each.

3.4.2 Critical Point Drying (CPD)

Afterwards, the dehydrated samples were transferred from the 100% Ethanol into the sample carrier, O-rings before they were loaded into the chamber insert of Critical Point Dryer (Brand Quorum/K850) as in Figure 3.3. The thumb screws of the chamber insert then were tightened properly. The chamber was primarily depressurised and pre-cool to +5°C for four minutes using the blue valve (chamber cooling) before operating. Then, the chamber was filled with Carbon Dioxide, CO₂ liquid by using the green inlet (chamber in) valve with a meniscus to the centre of the view window while the other valves are closed. At this point, the samples were soaked several times at least two times with a stirrer at +5°C for about three minutes each. Next, Carbon Dioxide, CO₂ the liquid was purged out from the chamber slowly and steadily at least mid-way on the view window by using the balance of inlet green (chamber in) and black valve (chamber out) while checking the presence of a damp patch with filter paper at the outlet of exhaust at rear instrument indicating solvent exchange

condition. Thereafter, the chamber was filled again with Carbon Dioxide, CO₂ liquid to the top of the upper red line. All valves were closed properly before the heater was switched on for the heating process of about 35 minutes at +35 °C and 1250 psi. Eventually, the chamber was depressurised completely to 0 psi by using a black exhaust valve (Non-delicate) and red bleed valve (Delicate) for about 20 minutes at 35°C. The O-rings carrying the samples then were transferred out from the chamber properly and ready for the next preparation.

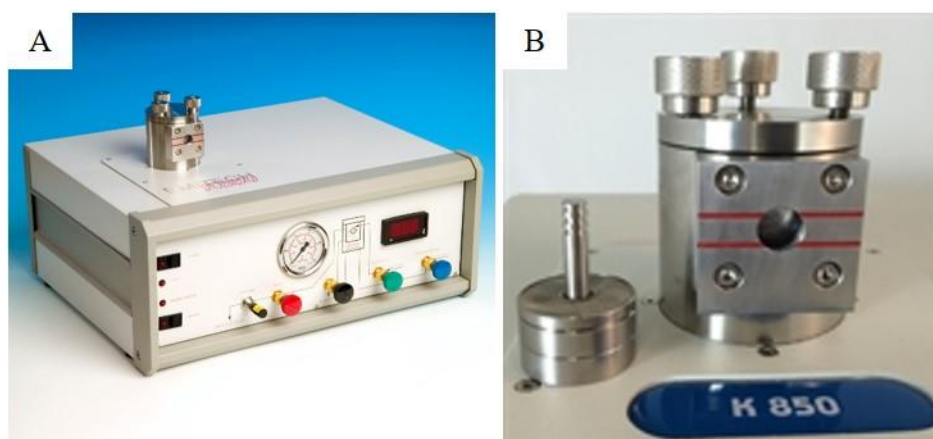


Figure 3.3: A. Critical Point Dryer (Brand Quorum/K850) with various key features to help the drying process of the samples for Field Emission SEM purposes. B. The chamber insert and the sample carrier, O-rings consist of 12 individual wells

3.4.3 Field Scanning Electron Microscopy Observation

Each dried sample of the *Nepenthes* studied was mounted carefully on the double-sided adhesive tape stick onto the labelled aluminium stub before they were coated with gold or platinum at about 30 nm of thickness on the top surface of the samples. The coating process was done using Auto Fine Coater (Jeol/JEC-3000FC) at a current of 20 mA in 80 seconds. Both mounting and coating processes were done properly as they were very crucial to ensure the electron transmission to the samples was well permitted. Next, the mounted and coated samples were arranged and adhered onto the specimen holder and placed into the

chamber of Field Emission Scanning Electron Microscopy (Jeol/JSM-IT500HR) for observation. The observation of the samples was done using different voltages either 5.0 kV or 10 kV to get better image resolutions. Also, the FESEM images of different micromorphological structures were observed and captured with different magnification values ranging from 50x to 20000x to get a clear view of the desired structures and better results. The images then were analysed based on the selected structures and parameters of the micromorphology listed in the Table 3.3. The structures were described with clarification from various related literary sources such as Owen and Lennon (1999), Hewson (2019), Schwallier et al. (2020), and Ghazalli et al. (2020; 2021).

Table 3.3: Selected structures and parameters for micromorphological analysis

Structures	Parameters
Epidermal layers	1. Type of stomata formation 2. Type of trichomes
Inner surface of the pitcher	1. Presence of lunate cells 2. Average length of lunate cells 3. Density of lunate cells 4. Average size of digestive glands 5. Density of digestive glands

3.5 Anatomical Study

The anatomical characteristics of each 13 collected *Nepenthes* taxa; *N. albomarginata*, *N. ampullaria*, *N. gracilis*, *N. hirsuta*, *N. hispida*, *N. mirabilis*, *N. mirabilis* var. *echinostoma*, *N. nazreeana* sp. nov. ined., *N. rafflesiana*, *N. reinwardtiana*, *N. x hookeriana*, *N. x kuchingensis*, and *N. x trichocarpa* were analysed based on several plant structures which are the abaxial and adaxial surfaces of mature leaves, and midrib using different methods by Cutler (1978) that were modified in sectioning and preparation. Three

replicates of the specimens were analysed from at least one to two individual per species or taxon collected from the field.

3.5.1 Epidermal Cuticular Sectioning and Preparation

The epidermal cuticles of the adaxial and abaxial of the mature *Nepenthes* leaves were cut into small portions about 1.5 cm x 1.5 cm by using a scalpel. Then, they were fixed and preserved in 7ml of Mc Cartney Bijou bottle containing 70% absolute Ethanol for at least 72 hours before use. After that, the samples were washed in the distilled water for 15 minutes before being immersed and boiled in the 15% Nitric acid, HNO₃ at 83°C until the abaxial and adaxial cuticle layers were separated from the leaves. The split cuticles were washed with distilled water and brushed gently using the paintbrush to remove the impurities left on the cuticle surface. Later, the split epidermal cuticles proceeded to the next preparation which involved staining and permanent slide preparation.

3.5.2 Midrib Transverse Sectioning and Preparation

The midrib of the *Nepenthes* studied at the middle part of the matured leaves were initially cut into portions about 1.5 cm-2.0 cm long and they were fixed in 70% Ethanol. The fixed samples then were washed in distilled water before proceeding with the transverse sectioning using a sliding microtome (Leica/SM2000R). The midrib of each *Nepenthes* was clamped with potato and screwed at the specimen holder to ensure the samples are not moving while sectioning. Then, they were cut slowly using the blade with a thickness of 10-15 µm. The sectioned samples were washed with distilled water to avoid contamination and subsequently prepared according to the staining and preparation of permanent slide procedures.

3.5.3 Staining and Permanent Slide Preparation

After thorough cleaning and washing, the epidermal layers and midrib samples of the *Nepenthes* studied were further bleached in the 70% Clorox for three minutes to remove the excess obscurities on the surface. Then, they were rinsed with distilled water three times before proceeding with the staining. All the samples were subsequently transferred to a petri dish containing permanent staining, Safranin O for 10-15 minutes. Moreover, the sections of midrib and petiole were stained again with Alcian Blue solution to reveal particular cells for analysis. Afterwards, all of them were then dehydrated in a series of Ethanol concentrations for three minutes each starting from 50%, 60%, 70%, 80%, 90% and 100%. Meanwhile, one to two drops of concentrated Hydrochloric acid, HCl were added to the 70% ethanol to obtain the colour balance. Once the dehydration process is done, the samples were transferred gently from the 100% ethanol onto the microscope slide. The samples were laid flat before applying one to two drops of the mounting media, Canada balsam on it. Next, the samples were pressed permanently using the covers slips and baked in the oven at 60°C or air dried for seven to eight days to thoroughly dry the mounting media before observing it under the compound microscope.

3.5.4 Samples Observation Under the Compound Microscope

All the samples prepared for the anatomical study were observed under a compound microscope (Olympus Advanced Research Microscope/BX51-CCD-DA) with different magnifications which are 10x, 20x, and 40x to view clear structures of the epidermal cuticular as well as the midrib sections. The data images were captured using the attached DP72 Olympus video camera to the microscope with the aid of Cell-DX 15 software. Then, the measurement of the structures was done using ImageJ software. The anatomical characteristics of the epidermal layers and the midrib (Table 3.4) were analysed with the aid

of several anatomical literatures by Metcalfe and Chalk (1950), Cutler et al. (2007), Al Farishy et al. (2016), Crang et al. (2018), Rizqiani et al. (2018), and Ghazalli et al. (2020; 2021).

Table 3.4: The structures and parameters of *Nepenthes* anatomical analysis

Plant Structures	Parameters
Epidermal layers (Abaxial and Adaxial surfaces)	1. Shape of epidermal cell 2. Type of anticlinal wall 3. Occurrence of stomata 4. Stomatal complex type 5. Stomatal size 6. Stomatal density 7. Glandular structures
Midrib	1. Midrib Outer Shape 2. Type of vascular bundles 3. Vascular bundle arrangement

3.6 Palynological Study

The pollen grains were obtained from the fresh sample of the male inflorescence of five *Nepenthes* studied; *N. ampullaria*, *N. gracilis*, *N. mirabilis*, *N. rafflesiana*, and *N. reinwardtiana*. The anther heads of the male flower were cut off from the androphore, put into the tea bag and air-dried in the zip lock bag containing silica gel for 24 hours. Another method was done by using preserved flowers in 70% ethanol. The anther part of the flowers was initially rinsed with distilled water and immersed in the glucose water for about three to five minutes. Then, they were rinsed again with distilled water to remove excess glucose before being air-dried. Afterwards, the pollen grains were brushed off gently from their anther head onto the double-sided adhesive tape mounted on the aluminium stub. Its anther head was mounted as well to observe the position of pollen grains on it.

The samples then were coated with platinum using Auto Fine Coater (Jeol/JEC-3000FC) at a current of 20 mA in 80 seconds. Next, the coated and mounted anther head and pollen grains were adhered onto the specimen holder and inserted into the Field Emission Scanning Electron Microscopy chamber for observation and examination. The images of the pollen grains and anther head were subsequently captured at various magnifications and different voltages to view the structures. The image data of the pollen grains then were analysed and described based on the pollen features such as aperture type and exine sculpturing, pollen unit and shape as well as the pollen tetrad size. The measurement of the pollen grains was done using ImageJ software. The results then were compared briefly with the results of the palynological study of Bornean *Nepenthes* reported by Adam et al. (1999) for identification.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Distribution

The sample collections of *Nepenthes* were conducted at western Sarawak which focused on four divisions; Kuching, Samarahan, Serian, and Sri Aman. A total of 18 taxa of *Nepenthes*; comprising 13 species, one variety, and four natural hybrids were recorded. They are widely distributed throughout western Sarawak but few species are very localized to a specific location. Thirteen taxa were collected from different localities that include Totally Protected Areas (National Parks, Nature Reserves and Wildlife Sanctuary), as well as forest reserves and disturbed areas/forests. Collection activities were conducted randomly in forested areas and likewise based on information from the literature and reports. While, the five *Nepenthes* taxa, namely, *N. bicalcarata*, *N. northiana*, *N. tentaculata*, *N. veitchii*, and *N. x bauensis* were based on data from the herbarium specimens deposited in SAR. The distributions of taxa are illustrated in Figure 4.1 and the list of 18 recorded and reported *Nepenthes* taxa is tabulated in Appendix A.

Four common species; *N. ampullaria*, *N. gracilis*, *N. mirabilis*, and *N. rafflesiana* were the most collected and recorded species in this study. These species are widely distributed in western Sarawak and can be found in a diverse range of locations, especially in Kuching, and Samarahan divisions. Three natural hybrids, *N. x hookeriana*, *N. x kuchingensis*, and *N. x trichocarpa* were encountered and distributed in the locations where their parent plants co-exist. Another two common species; *N. albomarginata* and *N. reinwardtiana*, were recorded from a few localities mainly in TPA areas in Kuching division.

Meanwhile, *N. tentaculata* was previously discovered in different places located in three divisions which are Kuching, Serian, and Sri Aman only.

Five endemic species of Sarawak were recorded in the western part of the state, which are *N. hispida*, *N. mirabilis* var. *echinostoma*, *N. nazreeana* sp. nov. ined., *N. northiana* and natural hybrid, *N. x bauensis*. Cheek and Jebb (2001) enlightened that *N. northiana* is known to be restricted to the limestone areas of Bau and Padawan in Kuching division. The remaining three taxa, *N. bicalcarata*, *N. hirsuta* and *N. veitchii* were identified as Bornean endemic and also can be found in western Sarawak. *Nepenthes bicalcarata* was reported from Serian and Sri Aman, *N. hirsuta* in Kuching, and *N. veitchii* in both divisions.

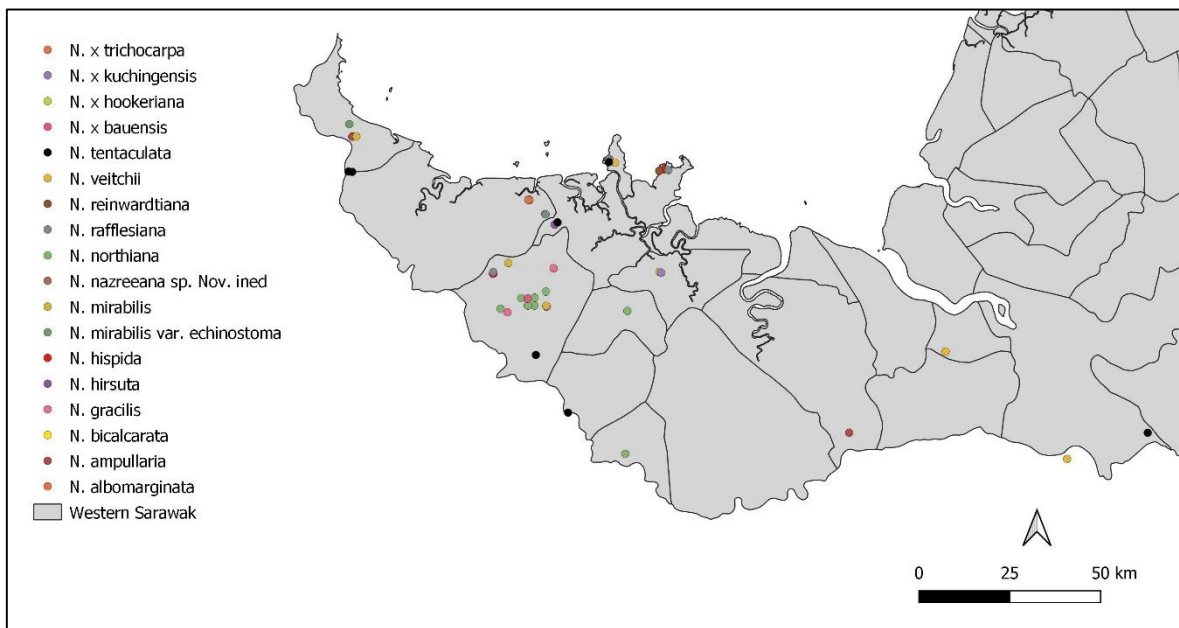


Figure 4.1: Distribution map of *Nepenthes* studied in western Sarawak

4.2 Habitat and Ecology

4.2.1 Habitat

The recorded and reported 18 *Nepenthes* taxa were found thriving in various vegetation, for instance, *kerangas* forest or heath forest, mixed dipterocarp forest, peat swamp forest, limestone forest, sandstone plateau, submontane forest, montane forest and disturbed areas/forest, such as roadside embankments (Figure 4.2). These diverse vegetation or forest types are common in Sarawak and, Tawan et al. (2008) reported that these forests are influenced by several factors including soil type, altitude, topography, climate, and geology.

The result shows that most of the *Nepenthes* taxa were commonly found thriving well in Kerangas Forest. Kerangas forest is common in Borneo and the word *Kerangas* was derived from Iban word means ‘land on which rice cannot be grown’ (Richards, 1996). The acidity of soil and deficiency in nutrients in soil types of *Kerangas* forest favour the need for *Nepenthes* to grow well in the area. Among the studied *Nepenthes*, 16 taxa grow in the Kerangas forest; *N. albomarginata*, *N. ampullaria*, *N. bicalcarata*, *N. gracilis*, *N. hirsuta*, *N. hispida*, *N. mirabilis*, *N. mirabilis* var. *echinostoma*, *N. nazreeana* sp. nov. ined, *N. rafflesiana*, *N. reinwardtiana*, *N. tentaculata*, *N. veitchii*, *N. x hookeriana*, *N. x kuchingensis*, and *N. x trichocarpa*. *Nepenthes albomarginata*, *N. gracilis* and *N. rafflesiana* were discovered to grow in the coastal area of Kerangas forest at the sandstone plateau area.

Among these taxa, *N. ampullaria*, *N. gracilis*, *N. mirabilis*, *N. nazreeana* sp. nov. ined., and *N. rafflesiana* were the common species that are usually can be found in the sun-exposed sites in the disturbed areas such as the roadside embankments or disturbed forest for road development purposes. *N. ampullaria* also was encountered growing in wet and shady areas in mixed dipterocarp forests along with *N. hirsuta*, *N. hispida*, *N. rafflesiana* and

sometimes with *N. gracilis*. Peat swamp forest also was a favourite environment for a few taxa such as *N. ampullaria*, *N. bicalcarata*, *N. gracilis*, and *N. mirabilis*.

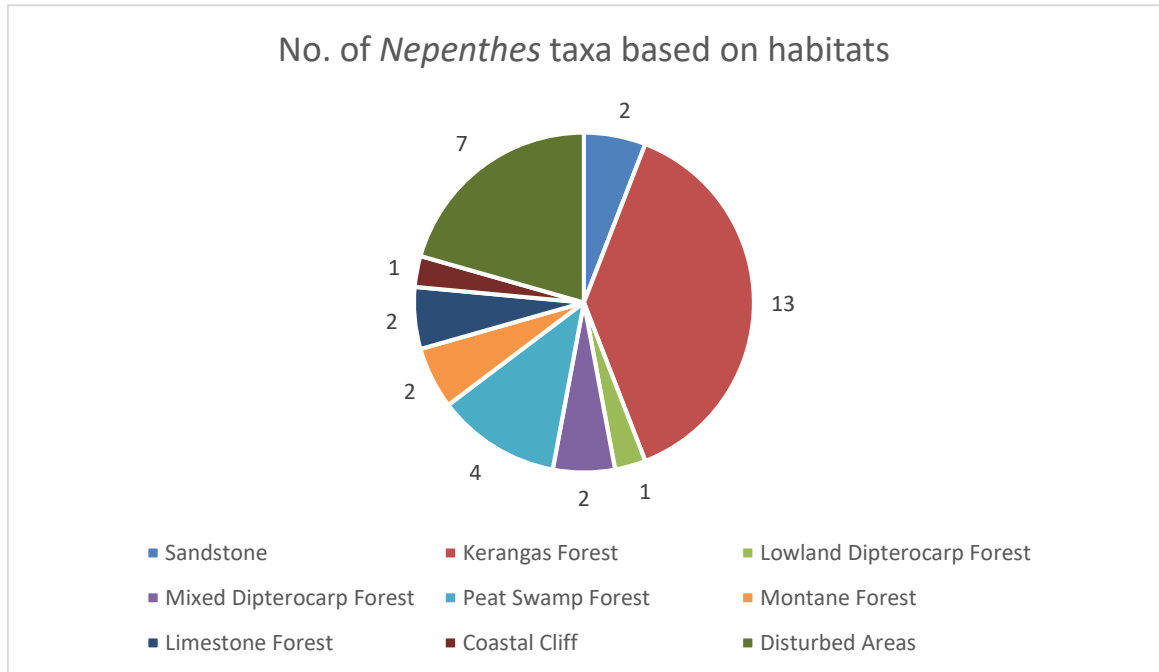


Figure 4.2: Number of *Nepenthes* taxa based on habitats

Nepenthes northiana was seen and reported inhabiting the inaccessible limestone cliff at Wind Cave, Bau, Kuching Division and several localities based on the SAR herbarium specimens. This species usually grows on the rock surface at the steep slope of the limestone hill. Also known as a lithophyte, this species was catalogued as an obligate limestone endemic species by Cheek and Jebb (2001) and Lee (2004b). A natural hybrid, *N. x bauensis* (*N. gracilis* x *N. northiana*) also can be found growing in the limestone area where its parent plants co-exist. *Nepenthes reinwardtiana* also was recognized as lithophytes. This species was found scrambling and hanging on the other plants on the sandstones at the coastal cliffs in Bako National Park. *Nepenthes tentaculata* and *N. veitchii* are often found in the mossy area of montane or submontane forests in highland areas.

Besides, the *Nepenthes veitchii* also can be found in the limestone area, kerangas forest, and lowland dipterocarp forest. The ecological data of *Nepenthes* were included in Table 4.1.

Table 4.1: Ecology of *Nepenthes* in western Sarawak

<i>Nepenthes</i> Taxa	Type of Forest/Habitat	Elevation (m.a.s.l)	pH	Moisture of Soil (%)
<i>N. albomarginata</i>	ST, KF	100 – 850 m	5.0	7.8
<i>N. ampullaria</i>	KF, MDF, PSF & DA	50 – 800 m	5.0 – 6.0	3.8 - 7.8
<i>N. bicalcarata</i>	PSF	0 – 500 m	*N/A	*N/A
<i>N. gracilis</i>	KF, MDF, PSF & DA	50 – 200 m	5.2-6.6	7.5
<i>N. hirsuta</i>	KF	150 – 800 m	6.0-6.4	7.5-8.5
<i>N. hispida</i>	KF	150 – 250 m	6.0 – 6.4	7.5 – 8.5
<i>N. mirabilis</i>	KF, PSF, DA	50 – 100 m	5.0 – 6.0	7.5 – 8.0
<i>N. mirabilis</i> var. <i>echinostoma</i>	KF	50 – 100 m	5.0 – 6.0	7.5 – 8.0
<i>N. nazreeana</i> sp. nov. ined.	DA, KF	50 m	6.6	3.8
<i>N. northiana</i>	LF	100 m	*N/A	*N/A
<i>N. rafflesiana</i>	KF, DA	50 – 250 m	6.6	3.8 - 8.8
<i>N. reinwardtiana</i>	ST, CC	Sea level to 100 m	*N/A	*N/A
<i>N. tentaculata</i>	KF, MF	800 – 3500 m	*N/A	*N/A
<i>N. veitchii</i>	KF, LF, LDP, MF	560 – 2500 m	*N/A	*N/A
<i>N. x bauensis</i>	LF	100 m	*N/A	*N/A
<i>N. x hookeriana</i>	DA, KF	50 – 100 m	5.0-6.0	3.8 – 4.0
<i>N. x kuchingensis</i>	PSF, KF	50 – 100 m	5.0-6.0	7.5
<i>N. x trichocarpa</i>	DA	50 – 100 m	5.0-6.0	3.8 – 4.0

Notes: Coastal Cliff (CF), Disturbed Areas (DA), Kerangas Forest (KF), Limestone Forest (LF), Lowland Dipterocarp Forest (LDF), Mixed Dipterocarp Forest (MDF), Montane Forest (MF), Peat Swamp Forest (PSF), Lowland Dipterocarp Forest (LDF), Sandstone (ST), Disturbed Forest (DF), Information is not available (N/A), Meter above the sea level (m.a.s.l)

4.2.2 Elevational distribution

These studied *Nepenthes* taxa can be categorized into two groups, viz, lowland group (≤ 1000 m.a.s.l) and highland group (≥ 1000 m.a.s.l) based on Adam et al. (1992). Majority of the recorded and reported *Nepenthes* taxa including the natural hybrids; *N. albomarginata*, *N. ampullaria*, *N. bicalcarata*, *N. gracilis*, *N. hirsuta*, *N. hispida*, *N. mirabilis*, *N. mirabilis* var. *echinostoma*, *N. nazreeana* sp. nov. ined., *N. rafflesiana*, *N. reinwardtiana*, *N. northiana*, *N. x bauensis*, *N. x hookeriana*, *N. x kuchingensis*, and *N. x trichocarpa* are classified under the lowland group with altitudes below 800 m. Only two taxa; *N. tentaculata* and *N. veitchii* were reported growing above 800 m and are classified as a highland group. However, based on the SAR herbarium specimen, *Nepenthes veitchii* can inhabit different ranges of elevation from lowland as low as 560 m to highland elevation at 2500 in western Sarawak.

4.2.3 pH and moisture of soil.

The pH and moisture of the soil of the *Nepenthes* habitat were measured by using Takemura DM-15 Soil pH & Moisture meter. The range of acidic soil is < 7.0 , neutral soil is 7.0 , and alkaline soil is > 7.0 . Meanwhile, the moisture of the soil is considered wet in the range of $1.0 - 8.0\%$ and below the minimum range is considered dry soil. The results show that the 13 recorded *Nepenthes* thrive in acidic soil with a low pH range between 5.0 to 6.4 with moisture approximately between 3.8 to 8.0% . The pH of soil and moisture are the ecological factors besides the type of habitat and its elevation, that could contribute to the growth and development of *Nepenthes* (Nabilah Huda et al., 2023). Most of the *Nepenthes* prefer to grow in wet and acidic soils, but, Cheek and Golos (2019) however, discovered few taxa were also can adapt and thrive well in highly alkaline soil conditions in limestone areas.

For instance; *N. ampullaria*, *N. gracilis*, *N. lowii*, *N. mirabilis*, *N. stenophylla*, *N. tentaculata*, *N. veitchii*, *N. vogelii*, and others.

4.3 Morphology of *Nepenthes* L.

A total of 18 *Nepenthes* taxa were morphologically described in detail herein. The morphology of stem, leaves, pitcher, inflorescences or infructescences were included.

4.3.1 The Stem Morphology

All *Nepenthes* have woody stems, and two stem shapes: cylindrical/terete, and angular. Twelve of the 18 *Nepenthes* studied had cylindrical/terete stems; *N. albomarginata*, *N. ampullaria*, *N. bicalcarata*, *N. hirsuta*, *N. hispida*, *N. mirabilis*, *N. mirabilis* var. *echinostoma*, *N. nazreeana*, sp. nov. ined., *N. rafflesiana*, *N. veitchii*, *N. x hookeriana*, and *N. x kuchingensis*. The stem of *N. tentaculata* was observed as cylindrical, but sometimes can be found in slightly angular. Meanwhile, the stems of the remaining five taxa, *N. gracilis*, *N. northiana*, *N. reinwardtiana*, *N. x bauensis* and *N. x trichocarpa* have three to four angular shapes. Table 4.2 contains measurements such as the diameter of stems and the length of the internodes.

Table 4.2: The morphological characteristics of *Nepenthes* stem

<i>Nepenthes</i> taxa	Shape of stem	Diameter of stem (mm)	Length of internodes (cm)
<i>N. albomarginata</i>	Cylindrical	3.43–10	1 – 2
<i>N. ampullaria</i>	Cylindrical	4.56–8.6	0.5– 6.5
<i>N. bicalcarata</i>	Cylindrical	10–12	1.20–2
<i>N. gracilis</i>	Triangular	2.8–4.8	2.0–7.7
<i>N. hirsuta</i>	Cylindrical	3.8–5.2	0.5–2
<i>N. hispida</i>	Cylindrical	3.5–5	0.5–1
<i>N. mirabilis</i>	Cylindrical	6–7	1.5–6
<i>N. nazreeana</i> sp. nov. ined.	Cylindrical	7.7–9.4	3–15
<i>N. northiana</i>	Angular	4–15	3–7.5
<i>N. rafflesiana</i>	Cylindrical	6.9–12.2	1.5–7.5
<i>N. reinwardtiana</i>	Triangular	3.5–4	1– 3
<i>N. tentaculata</i>	Cylindrical-angular	ca. 2	0.4 – 1.5
<i>N. veitchii</i>	Cylindrical	5–7	2–4
<i>N. x bauensis</i>	Angular	3–3.5	3–4.5
<i>N. x hookeriana</i>	Cylindrical	ca. 11.2	ca. 0.5
<i>N. x kuchingensis</i>	Cylindrical	3.42–5	ca. 0.5
<i>N. x trichocarpa</i>	Angular (triangular)	3.2–3.7	2– 4.5

The stems of *N. albomarginata*, and *N. veitchii* were found to be flexuose. The stems grow curved or bent. Aside from that, three taxa have wings on the stem, including *N. gracilis*, *N. reinwardtiana*, and *N. northiana*. *Nepenthes northiana* forms saddle-shaped wings on its rounded to 4-angular from the base of the leaves, whereas, *N. gracilis* and *N. reinwardtiana* have smaller wings up to 4 mm wide on their triangular stem.

The diameter of the stems in *Nepenthes* were varied. The observations showed that *N. tentaculata* has the smallest diameter of the stem with ca. 2 mm diam., followed by *N.*

gracilis, *N. x trichocarpa*, *N. x kuchingensis*, *N. reinwardtiana* with 2.8–4.8 mm, 3.2–3.7 mm, ca. 3.42 mm and 3.5–4 mm, correspondingly. Meanwhile, the biggest diameter stem can be observed in *N. northiana* with 4–15 mm diam., followed by *N. rafflesiana*, *N. mirabilis* var. *echinostoma*, and *N. x hookeriana* with 6.9–12.2 mm, 6.70–11.40 mm and ca. 11.2 mm respectively.

The lengths of the internodes of *Nepenthes* studied were measured. Mostly the internodes of *Nepenthes* stem at the upper part are longer than the internodes at the lower part. The results show that *N. nazreeana* sp. nov. ined has the longest internodes compared to the others with a length of approximately 15 cm. Whereas, the shortest internodes can be observed in several *Nepenthes* taxa with lengths between 4 – 5 mm, such as *N. ampullaria*, *N. hispida*, *N. hirsuta*, *N. tentacula*, *N. x hookeriana* and *N. x kuchingensis*.

4.3.2 Leaf Morphology

The leaves of *Nepenthes* have several characteristics that support in taxonomic classification. The leaves of the 18 *Nepenthes* taxa studied were found to be slightly similar in colour, ranging from light green to green, or dark shiny green. Sometimes, they were spotted or blotches with red colour. They do, however, have slightly different green colours on the abaxial and the adaxial surface of the leaves in each species. The colour of the adaxial surfaces is typically lighter compared to the abaxial surface.

Furthermore, the leaves of all *Nepenthes* studied were observed to have two types of veins which are pennate veins and longitudinal veins. The pennate veins are numerous and appear to be angled at 45° or 90° from the midrib toward the apex. However, they are usually inconspicuous. Meanwhile, the longitudinal veins are usually conspicuous and can be seen on the abaxial surfaces of leaves along the midrib near the margin. The number of longitudinal veins varies ranging from one to ten veins, or sometimes more at each side of

the midrib. Jebb (1991) explained that both types of veins can provide significant characteristics and can be diagnostic in some geographical areas.

4.3.2.1 Shape, Apex, and Base of Leaves

The majority of the *Nepenthes* leaves taxa studied had intermediate characteristics between two leaf-shaped. Six shapes were observed and described; elliptic, lanceolate, oblanceolate, oblong, obovate, and spatulate (Figure 4.3).

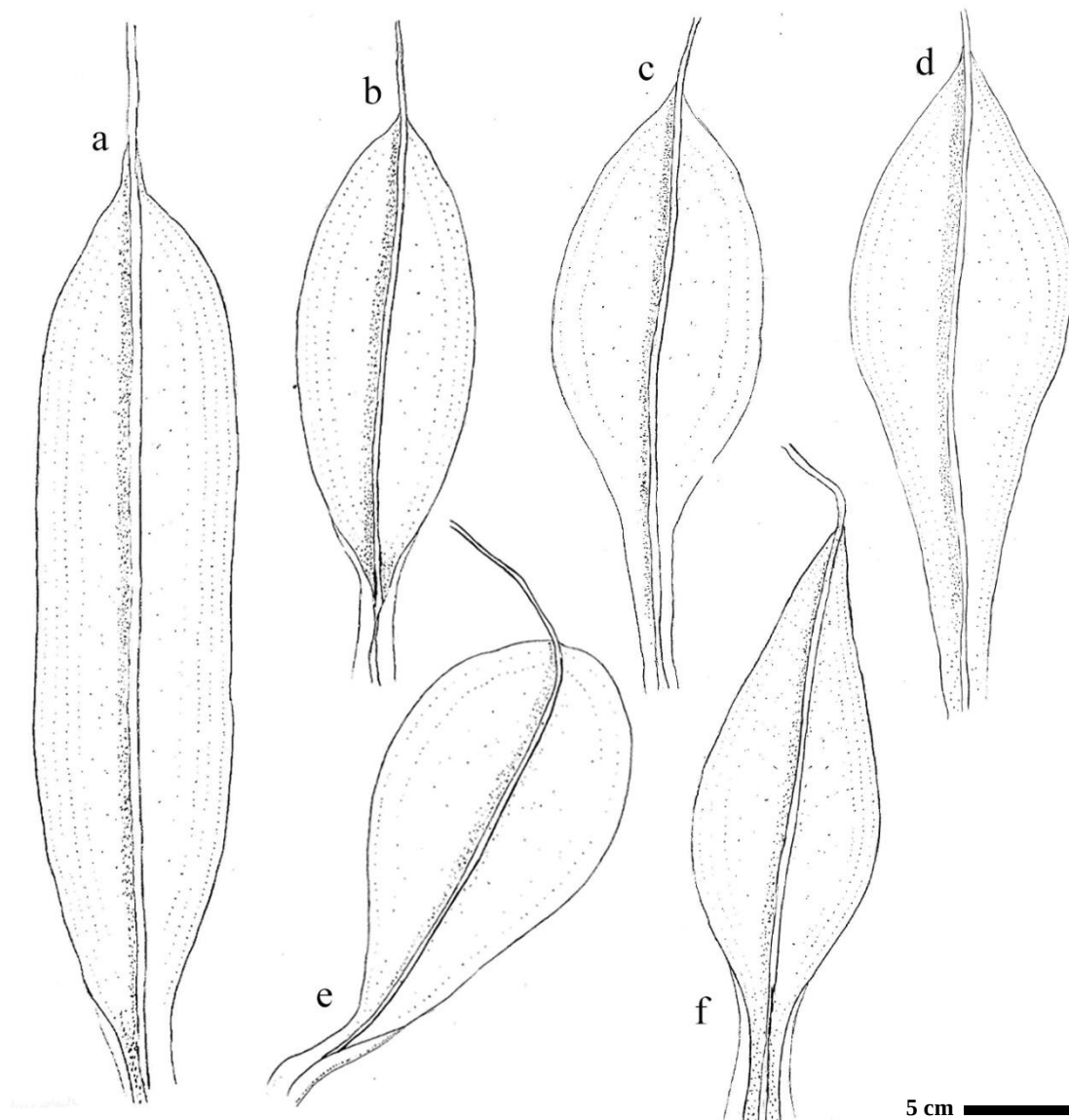


Figure 4.3: Leaf Shapes of *Nepenthes* studied. (a) oblong (b) elliptic (c) spatulate (d) oblanceolate (e) obovate (f) lanceolate. Illustration by Nabilah Huda, M. H.

Nepenthes gracilis and its natural hybrid, *N. x trichocarpa* possess a narrowly lanceolate and slightly similar shape, and narrowly lanceolate with slightly oblanceolate in a later taxon. Other natural hybrid, *N. x kuchingensis* forms an oblanceolate shape of leaf whereas, *N. reinwardtiana* has narrowly elliptical leaves. Three taxa, *N. bicalcarata*, *N. mirabilis* and *N. mirabilis* var. *echinostoma* have lanceolate to oblong shapes in both upper and lower pitcher plants. But, the obovate shape was also noticed in the leaves of the lower part of *N. mirabilis*. Other taxa such as *N. hispida* and *N. rafflesiana* share similar characteristics which are oblanceolate to oblong shapes. The closest relative species of *N. hispida*, *N. hirsuta* exhibit different leaf shapes oblanceolate at the lower pitcher plant and narrowly elliptic at the upper pitcher plant. Also, *N. x hookeriana* forms lanceolate to elliptical shapes in its leaves.

The most common species, *N. ampullaria* was observed forming lanceolate to spatulate shaped, while *N. albomarginata* has narrowly oblanceolate to spatulate shaped. Besides, the leaves of the limestone endemic taxa such as *N. northiana* appear in elliptic to spatulate shape (lower pitcher plant), and narrowly oblong (upper pitcher plant). The natural hybrid, *N. x bauensis* form intermediate characteristic between its parent plant which reveals narrowly lanceolate to slightly oblong-lanceolate. *Nepenthes tentaculata* shows an elliptical to oblong shaped, whereas *N. veitchii* has obovate to oblanceolate leaves. The average sizes of the *Nepenthes* leaves were measured and the data were included in Table 4.3.

Table 4.3: Leaf morphological characteristics of *Nepenthes* studied in western Sarawak

<i>Nepenthes</i> taxa	Shape	Size of lamina (cm)		Apex	Base
		Length	Width		
<i>N. albomarginata</i>	narrowly oblanceolate - spathulate	10.2 – 14.2	1.3 – 1.6	acute	abruptly narrower or gradually tapered
<i>N. ampullaria</i>	lanceolate-spathulate	4.4 - 33.3	1.3 – 7.4	acute-acuminate	attenuate
<i>N. bicalcarata</i>	oblong-lanceolate	48.76 – 56	11.47 -12.78	acute	attenuate
<i>N. gracilis</i>	narrowly lanceolate	9.4 – 14.6	2.2 – 2.75	acute	slightly narrowing to the stem.
<i>N. hirsuta</i>	oblanceolate (LP), narrowly elliptic (UP)	3.0 – 21	1 – 5.7	acute	tapered
<i>N. hispida</i>	oblanceolate– oblong	5 – 10	1 – 3	acuminate – obtuse	narrowly tapered
<i>N. mirabilis</i>	lanceolate-oblong (LP), lanceolate-oblong and obovate (UP)	6.7 – 16.9	3 – 6	acute-acuminate	slightly cuneate
<i>N. mirabilis</i> var. <i>echinostoma</i>	lanceolate-oblong	8.5 – 32	3.5 – 8	acute-acuminate	slightly cuneate
<i>N. nazreeana</i> sp. nov. ined.	elliptic - oblanceolate	11.7 – 26.8	5.6 - 9.5	obtuse to very slightly truncate	rounded to slightly truncate
<i>N. northiana</i>	elliptic-spathulate (LP), narrowly oblong (UP).	7.8 – 49.8	2 – 11	apex acute, with tendril peltate	attenuate

LP (Lower pitcher plant), UP (Upper pitcher plant)

Table 4.3 continued

<i>N. rafflesiana</i>	narrowly oblong-ob lanceolate	10.5 – 58	2.2 - 9	acute-acuminate	acute-attenuate
<i>N. reinwardtiana</i>	narrowly elliptic.	7.1 – 14	1.9 – 2.4	acute	attenuate
<i>N. tentaculata</i>	elliptical- oblong	3 – 13.3	1 – 3	acute	slightly Cordeate, sub-perfoliate
<i>N. veitchii</i>	obovate- oblanceolate	5.2 – 30	2 – 8.2	truncate-retuse	Cuneate-obtuse
<i>N. x bauensis</i>	lanceolate to slightly oblong-lanceolate	16 – 18	2.5 – 3	acute	narrowing and decurrent into the stems
<i>N. x hookeriana</i>	lanceolate - elliptical	10 – 18	4.8 – 6.2	acuminate or slightly acute	cuneate
<i>N. x kuchingensis</i>	oblanceolate	8 – 25	2.3 – 5.8	acute or slightly acuminate	attenuate
<i>N. x trichocarpa</i>	narrowly lanceolate, slightly oblanceolate	5.2 – 16	1.2 – 3.2	Acute- acuminate	narrowing to the stem, decurrent into the stem

 LP (Lower pitcher plant), UP (Upper pitcher plant)

The leaves of *Nepenthes* studied were measured from the leaf apex to the base. Based on the observations, the longest leaves were *N. northiana* with an average measurement of 11 cm, while the shortest leaves were *N. tentaculata* with an average of 13.3 cm. The widths of the leaves were measured at the widest part of the leaves which was usually at the half of the lamina. The widest leaves observed was also *N. northiana*, and the narrowest leaves were seen in *N. gracilis* and its natural hybrid, *N. x trichocarpa*.

The types of apex in *Nepenthes* studied are illustrated in Figure 4.4. The apex of leaves in the *Nepenthes* studied are mostly acute, or acute to acuminate. The acute apex can be seen in *N. albomarginata*, *N. bicalcarata*, *N. gracilis*, *N. hirsuta*, *N. northiana*, *N. reinwardtiana*, *N. tentaculata* and *N. x bauensis*. *Nepenthes northiana* shows an interesting characteristic where the tendril that protruded from the apex of the leaves is peltate. *Nepenthes x kuchingensis* also has acute apex, however, this species sometimes can be found to have a slightly acuminate apex. Meanwhile, other taxa such as *N. ampullaria*, *N. hispida*, *N. mirabilis*, *N. mirabilis* var. *echinostoma*, *N. rafflesiana*, and *N. x trichocarpa* have intermediate characteristics between acute to acuminate apex. A natural hybrid, *N. x hookeriana* has acuminate with a slightly acute apex. Differently from others, *N. veitchi* has truncate to retuse apex, and *N. nazreeana* sp. nov. ined. has obtuse to very slightly truncate at the apex.

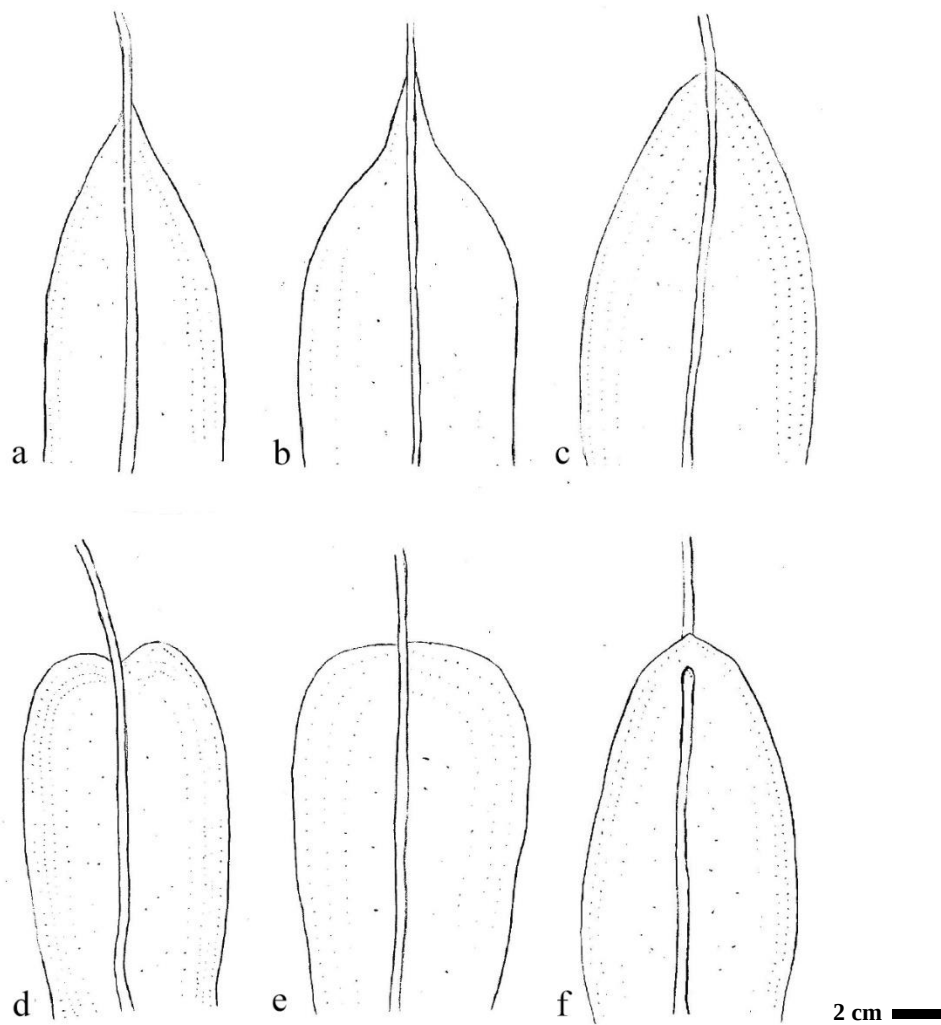


Figure 4.4: Leaf apex of *Nepenthes* studied. (A) acute (b) acuminate (c) obtuse (d) retuse (e) emarginate (f) sub-peltate. Illustration by Nabilah Huda, M. H.

The majority of the leaves in the *Nepenthes* taxa studied were observed with attenuate and cuneate bases. The attenuate base can be observed in several taxa such as *N. ampullaria*, *N. bicalcarata*, *N. northiana*, *N. rienwardtiana*, and *N. x trichocarpa*. The cuneate base can be seen in *N. mirabilis*, *N. mirabilis* var. *echinostoma*, and *N. x hookeriana*. The cuneate to obtuse base can be seen in *N. veitchii*. *Nepenthes rafflesiana* was observed having acute to cuneate in its base of leaves. *Nepenthes tentaculata* has a slightly cordate base with sub-perfoliate leaves which the stem passing through the leaf blade. The leaf bases of the

remaining taxa, *N. albomarginata*, *N. gracilis*, *N. hirsuta*, *N. hispida*, *N. x bauensis* and *N. x trichocarpa* are narrowing to the base or tapered slightly or gradually.

4.3.2.2 Petioles

The sessile petioles can be seen in *N. albomarginata*, *N. gracilis*, *N. hispida*, *N. reinwardtiana*, *N. tentaculata*, *N. x bauensis* and *N. x trichocarpa*. Most of the *Nepenthes* taxa are petiolate either with long petiole or short/poorly defined petiole. The long petiole can be observed in *N. mirabilis*, *N. mirabilis* var. *echinostoma*, *N. rafflesiana*, *N. nazreeana* sp. nov. ined., *N. veitchii*, *N. x hookeriana* and *N. x kuchingensis*. *Nepenthes ampullaria* rarely have long petioles as they are commonly found with a short or poorly defined petiole except for the rosette form as they are sessile.

The petioles are canaliculated and winged with different lengths. The ranges of petiole length of each taxon were included in Table 4.4. The longest petioles are in *Nepenthes veitchii* (19.5 cm) while the shortest can be seen in a short poorly defines petioles taxa, *N. ampullaria* and *N. hirsuta* with ca. 5 mm.

Table 4.4: Characteristics of petiole and leaf attachment in *Nepenthes* studied

<i>Nepenthes</i> taxa	Petioles		
	Types	Attachment	Length (cm)
<i>N. albomarginata</i>	sessile	not decurrent, clasping half of the stem circumference.	NA
<i>N. ampullaria</i>	sessile to short, poorly defined petiole, rarely long petiolate.	clasping half of the stem.	0.5 -5.0
<i>N. bicalcarata</i>	petiolate	clasping $\frac{3}{4}$ of the stem.	9.5 – 10
<i>N. gracilis</i>	sessile	decurrent into stem wings, clasping half of the stem.	NA
<i>N. hirsuta</i>	short, poorly defined petiole,	clasping $\frac{3}{4}$ of the stem circumference, amplexicaul	0.5 – 2.5

Table 4.4 continued

<i>N. hispida</i>	sessile	amplexicaul	NA
<i>N. mirabilis</i>	petiolate	canaliculate, clasping half of the stem.	2.5- 4.25
<i>N. mirabilis</i> var. <i>echinostoma</i>	petiolate	winged, clasping half of the stem.	4 – 8.5
<i>N. nazreeana</i> sp. nov. ined.	petiolate	clasping half of the stem circumference.	8.0 - 11.5
<i>N. northiana</i>	short, poorly defined petiole.	clasping half of the stem.	7.0 – 11.0
<i>N. rafflesiana</i>	petiolate	clasping half of the stem.	4.0– 17.0
<i>N. reinwardtiana</i>	sessile	leaf decurrent into the stem, clasping half of the stem	NA
<i>N. tentaculata</i>	sessile	amplexicaul	NA
<i>N. veitchii</i>	petiolate	clasping half of the stem.	1.5 – 19.5
<i>N. x bauensis</i>	sessile	clasping half of the stem.	NA
<i>N. x hookeriana</i>	petiolate	winged, clasping $\frac{3}{4}$ of the stem.	4.0 – 6.5
<i>N. x kuchingensis</i>	petiolate	clasping $\frac{3}{4}$ of the stem circumference.	NA
<i>N. x trichocarpa</i>	sessile	clasping half or $\frac{3}{4}$ of its circumference and decurrent into the stem.	NA

NA= Not Available

Several types of leaf attachments were observed in *Nepenthes* (Figure 4.5). All taxa have leaves clasping the stem at the base either with their leaf decurrent into the stem or not. Most of the taxa recorded were with leaves clasping the stem at half of its circumference, for instance, *N. albomarginata*, *N. ampullaria*, *N. gracilis*, *N. mirabilis*, *N. mirabilis* var. *echinostoma*, *N. nazreeana* sp. nov. ined, *N. northiana*, *N. rafflesiana*, *N. reinwardtiana*, *N. veitchii*, and *N. x bauensis*. The clasping $\frac{3}{4}$ or amplexicaul leaves attachment on the stems were observed in *N. bicalcarata*, *N. hirsuta*, *N. hispida*, *N. tentaculata* and the natural hybrids, *N. x hookeriana*, *N. x kuchingensis* and *N. x trichocarpa*. Furthermore, *Nepenthes*

tentaculata shows slightly different characteristics, in that sometimes the leaves are sub-perfoliate and the stem are passing through the leaves, while *N. northiana* forming saddle-like wings shape at the base.

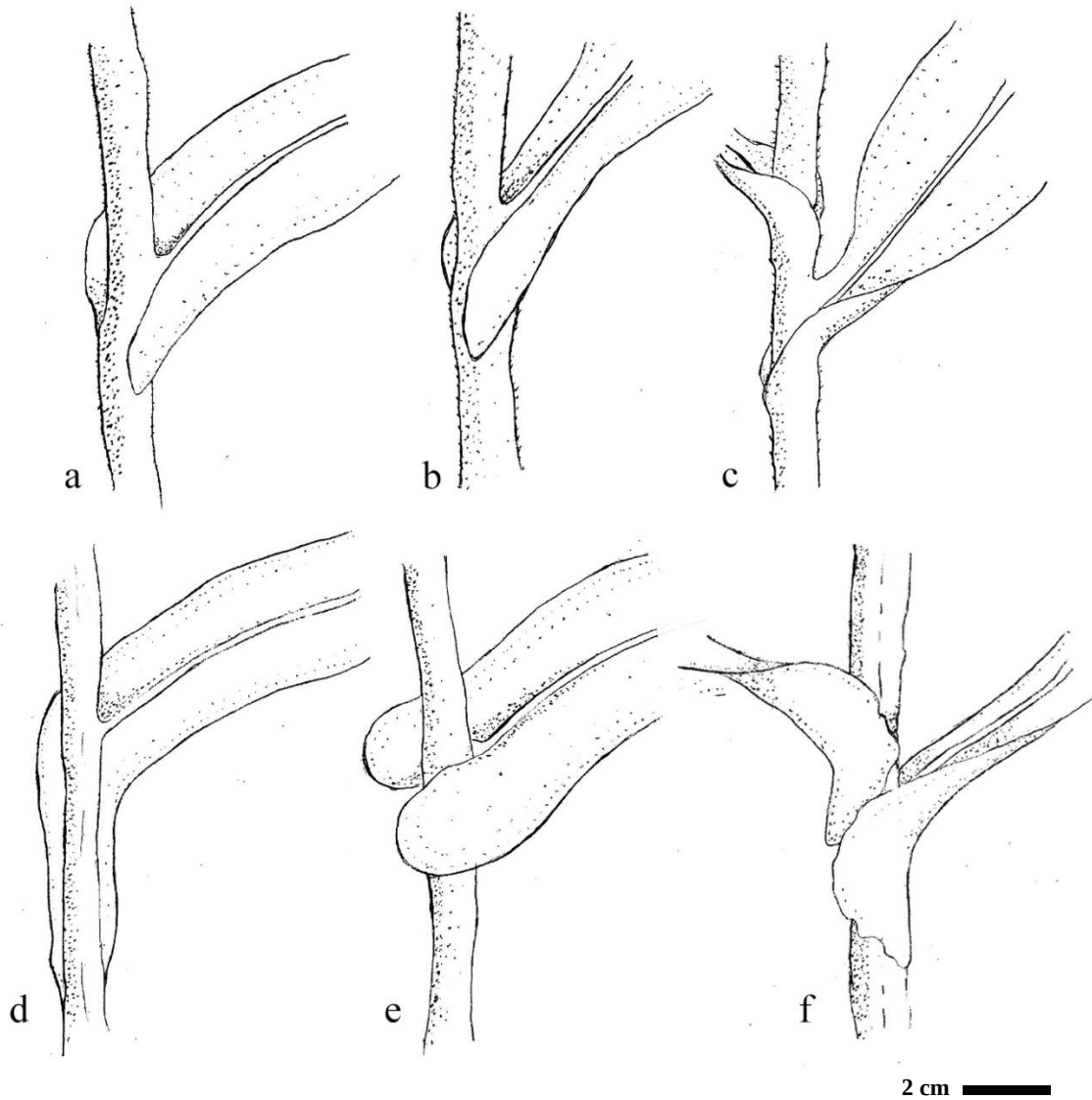


Figure 4.5: Leaf base attachments of *Nepenthes* studied. (a) half clasping of the stem circumference at the base (b) $\frac{3}{4}$ clasping at the base (c) amplexicaul (d) leaf decurrent into the stem at the base (e) sub-perfoliate (f) petiole with saddle-like wings shape. Illustration by Nabilah Huda, M. H.

4.3.2.3 Texture and Margin of Leaves

The leaves of *Nepenthes* studied were coriaceous and chartaceous in textures. Coriaceous or leathery textures are found in *N. albomarginata*, *N. hirsuta*, *N. hispida*, *N. nazreeana* sp. nov. ined., *N. northiana*, *N. rafflesiana*, *N. veitchii*, *N. x bauensis*, *N. x hookeriana* and *N. x trichocarpa*. Meanwhile, the remaining eight taxa have chartaceous or papery-like leaves; *N. ampullaria*, *N. bicalcarata*, *N. gracilis*, *N. mirabilis*, *N. mirabilis* var. *echinostoma*, *N. reinwardtiana*, *N. tentaculata*, and *N. x kuchingensis*.

The leaf margins of all *Nepenthes* are typically entire, with smooth and even margins throughout (Figure 4.6). A rosette form or lower pitcher plant of *N. mirabilis*, on the other hand, develops a fimbriate margin with fimbriae elements measuring *ca.* 1.0 mm. However, the climbing plant or upper pitcher plant of *N. mirabilis* is devoid of fimbriae elements.

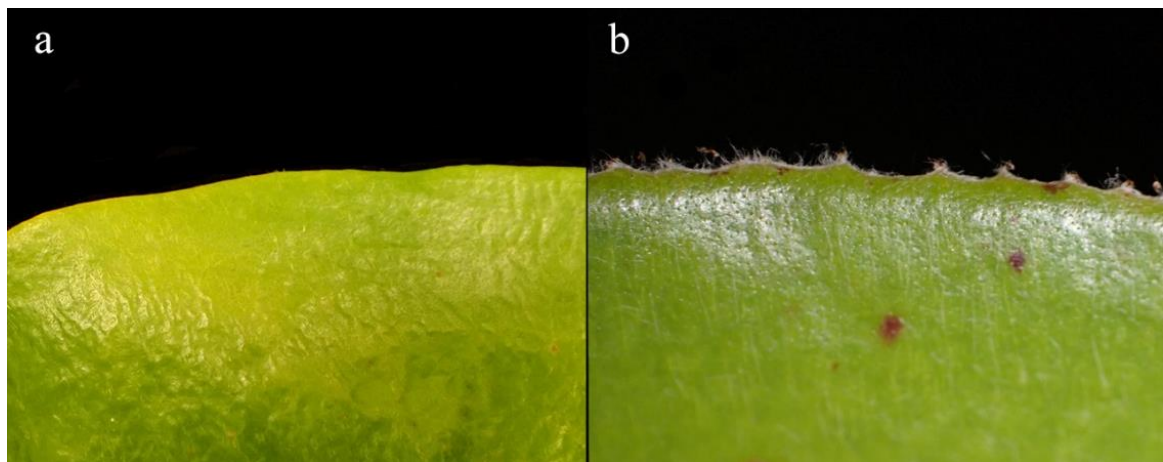


Figure 4.6: Type of margin in *Nepenthes*. (a) Entire margin (b) Fimbriate margin

4.3.3 Pitcher Morphology

Most of the identification of the *Nepenthes* studied were made based on the pitcher morphology. They are varied in shapes, sizes, and colours which play a significant role in attracting the prey. They exhibit two types of variation; interspecific diversity and intraspecific diversity. The pitcher morphology of 13 *Nepenthes* taxa studied; *N. albomarginata*, *N. ampullaria*, *N. gracilis*, *N. hirsuta*, *N. hispida*, *N. mirabilis*, *N. mirabilis* var. *echinostoma*, *N. nazreeana* sp. nov. ined., *N. rafflesiana*, *N. reinwardtiana*, *N. x hookeriana*, *N. x kuchingensis*, and *N. x trichocarpa* were observed and analysed based on the field specimens, and the remaining five taxa; *N. bicalcarata*, *N. northiana*, *N. tentaculata*, *N. veitchii*, and *N. x bauensis* were described based on the herbarium specimens deposited in SAR. The characteristics of the pitcher for each *Nepenthes* studied are elucidated in the Appendix B.

4.3.3.1 Pitcher shape

The *Nepenthes* studied also exhibit unique variation of pitcher among and within the taxa in different sizes, shapes and colours. Each taxa produces dimorphic pitchers which known as lower pitcher plant and upper pitcher plant. The lower pitcher plants and upper pitcher plants can be differentiated by several characteristics such as the habit of the plant, size and shape of pitcher, position of tendril, and size of peristome. Generally, the lower pitcher plants are bigger in size, and urceolate or globose in shape with presence of fringed wings compared to the upper pitcher plants. The upper pitcher plants developed infundibuliform or more narrow pitcher shape with two ridges instead of fringed wings at the frontal body.

The lower pitcher of *Nepenthes ampullaria* was observed producing globose pitcher shape, with flat to almost flat at the dorsal side, and ventral side. Meanwhile, the upper

pitcher plant rarely produced the upper pitcher compared to the other taxa. The lower pitcher plant of *Nepenthes bicalcarata* studied has a slightly similar shape, globose as *N. ampullaria*. But, both can be differentiated by the presence of two huge and sharply pointed thorns developed from the peristome apex of *N. bicalcarata*. *Nepenthes rafflesiana* possessed the most distinctive pitcher morphology between the upper pitcher and lower pitcher forms among the *Nepenthes* taxa studied. The lower pitchers of *Nepenthes rafflesiana* were developed in ovoid, or broadly ovoid to subglobose shape, while the upper pitchers were developed in infundibuliform, or narrowly infundibuliform shape (Figure 4.7 & Figure 4.8). These characteristics also were obvious in other taxa studied, such as *Nepenthes albomarginata*, *N. hirsuta*, *N. mirabilis* and *N. nazreeana* sp. nov. ined. (Figure 4.9).



Figure 4.7: (A-D) Intraspecific variation in lower pitcher plant of *Nepenthes rafflesiana*



Figure 4.8: (A-D) Intraspecific variation in upper pitcher plant of *Nepenthes rafflesiana*



Figure 4.9: Interspecific variation within the *Nepenthes* taxa studied. (A) LP of *N. albomarginata* (B) UP of *N. albomarginata* (C) LP of *N. hirsuta* (D) UP of *N. hirsuta* (E) UP of *N. nazreeana* sp. nov. ined. (F) LP of *N. nazreeana*, (G) LP of *N. mirabilis* (H) UP of *N. mirabilis*. LP = Lower Part, UP = Upper Part

Three taxa, *Nepenthes albomarginata*, *N. gracilis*, and *N. reinwardtiana* are slightly similar in their slender pitcher shape, and sometimes can be confused with each other (Figure 4.10). However, *N. albomarginata* can be directly distinguished from any other species by the presence of narrow white-collared band under the peristome. This white band is composed of stellate trichome that are densely formed around the beneath of the peristome. *Nepenthes reinwardtiana*, on the other hand shows a spot character, the two eye-spots on the inner surface of the pitcher wall, which are absence in the other two taxa, *N. albomarginata*, and *N. gracilis*. Phillips and Lamb (1996) reported that the eye spots character of *Nepenthes reinwardtiana* may be lacking or only one, or three eye-spots presence on the inner pitcher wall in certain population of the species. This unique character also has been observed in other taxa, such as *N. tentaculata*, *N. sanguinea*, and *N. stenophylla* as described by Clarke (1997), but they are not consistent.

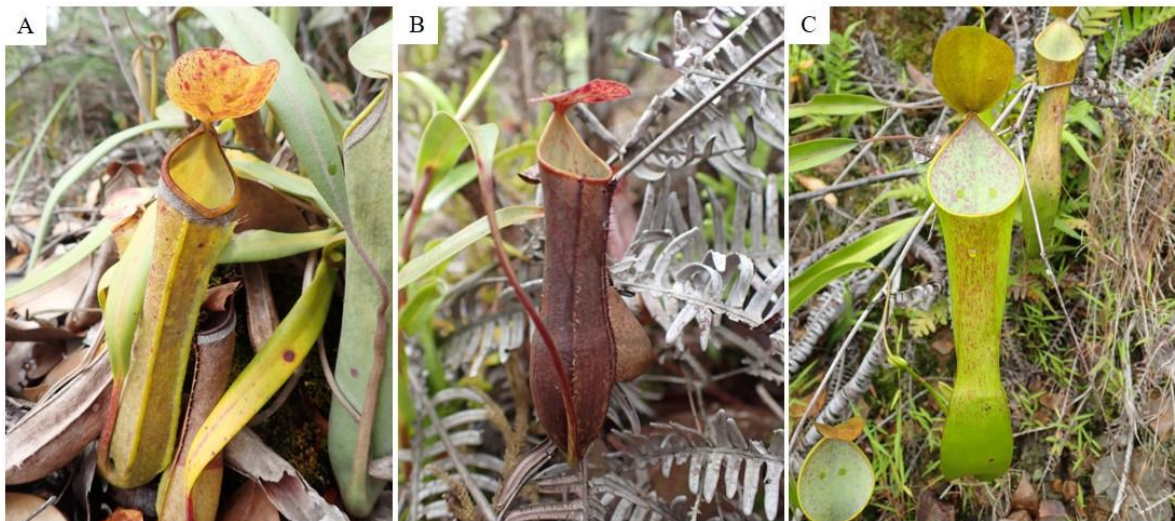


Figure 4.10: The slender shape of three *Nepenthes* taxa studied. (A) *N. albomarginata* (B) *N. gracilis* (C) *N. reinwardtiana*

The most widespread species, *Nepenthes mirabilis* usually has subcylindrical pitcher shape, with slightly ovoid at the basal half for lower pitcher plant, and with slightly flattened

laterally. They have a distinct ‘hipped’ point at the middle of the pitcher. These characters were observed as well in its variety, *N. mirabilis* var. *echinostoma*. But, the variety was distinguished immediately by the unique characteristics on its peristome.

The lower pitcher plant of *Nepenthes northiana* has a very huge ovoid shape and recumbent pitchers. Eventhough other taxon, *Nepenthes mapuluensis* shares this similar pitcher characteristics, *N. northiana* can be identified easily by its angular stem, and saddle-shaped wings on the stem at the leaf base (Jebb and Cheek, 2001). The other huge taxon, *Nepenthes veitchii* has a broadly cylindrical and broadest at the middle with two fringed wings.

4.3.3.2 Natural hybrids

Hybrids are crosses between two species of *Nepenthes*. The hybridisation in genus *Nepenthes* are common as they are dioecious, freely cross-compatible, and wind-dispersed (Thorogood, 2010). Many species of *Nepenthes* were found grow sympatrically in their habitat and sporadically produce natural hybrids. Four natural hybrids; *Nepenthes* x *bauensis*, *N. x hookeriana*, *N. x kuchingensis*, and *N. x trichocarpa* were observed and included in the study. These taxa forming intermediate characteristics between their parental plants (Figure 4.11). The parental plants of these four taxa are:

1. *N. albomarginata* x *N. northiana* = *N. x bauensis*
2. *N. ampullaria* x *N. x rafflesiana* = *N. x hookeriana*
3. *N. x ampullaria* x *N. mirabilis* = *N. x kuchingensis*
4. *N. ampullaria* x *N. gracilis* = *N. x trichocarpa*

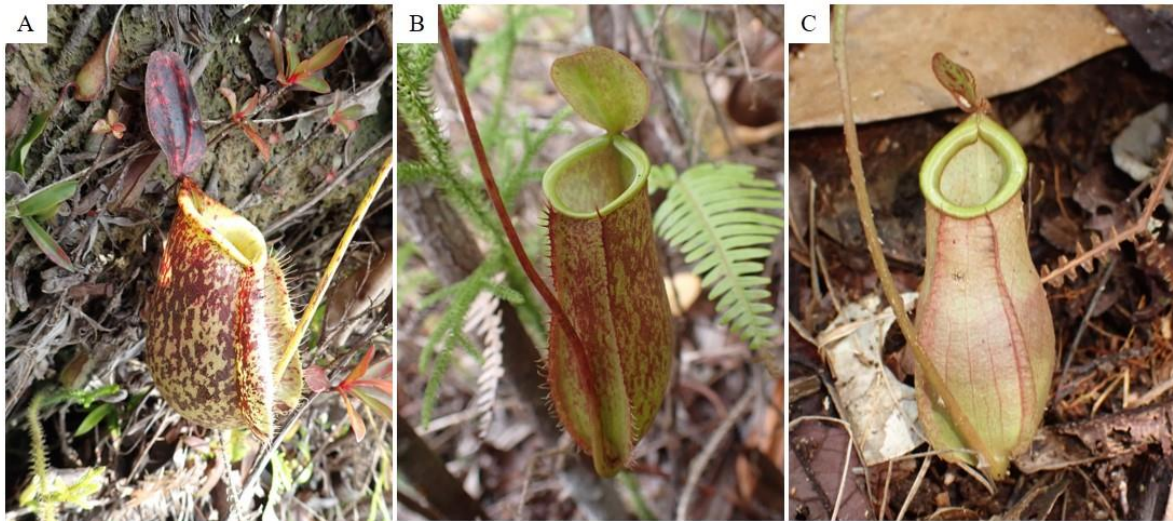


Figure 4.11: Examination of natural hybrids of *Nepenthes* pitchers studied insitu. (A) *N. x hookeriana*, (B) *N. x trichocarpa* (C) *N. x kuchingensis*

4.3.3.3 Colour

The colouration in plants such as *Nepenthes* are caused by the presence of different pigments. These pigments were classified into three classes; chlorophyll (green), anthocyanins (red, blue, purple, black), and carotenoids (yellow to red) (Schaefer and Rolshausen, 2005). The observation shows that most of the pitchers in *Nepenthes* studied revealed various bright colours, light green to green colour or yellowish green, and usually blotches, mottled, spotted, freckled, splashed or suffused with red to pinky red, or purple to dark purple. These colouration are caused by three pigments which serve several functions, e.g. green colour plays important role in photosynthesis (Croft & Chen, 2017), anthocyanin indicates the macro nutrient deficiency, especially nitrogen (N), and phosphorus (P) (Close & Beadle, 2003), and also related to the environmental factors, such as temperature and soil water (Steyn et al., 2002). In addition, Moran et al. (1999), and Bauer and Federle (2009) stated that striking or bold colour of *Nepenthes* pitcher usually appear at the part where the nectars are presence such as lid and peristome.

4.3.3.4 Sizes

The sizes of pitcher of *Nepenthes* studied are varied among the taxa. Among the taxa studied, the smallest pitcher was seen in *Nepenthes x trichocarpa*, and *N. gracilis*. Meanwhile, the biggest pitchers were observed in three taxa which are *Nepenthes rafflesiana*, *N. northiana*, and *N. veitchii*. The observations also revealed that the lower pitcher plant of the *Nepenthes* taxa studied usually are much bigger in size with globose shape, compared to the smaller upper pitcher plant in infundibuliform shape. A study by Handayani and Hadiah (2019) on a *Nepenthes mirabilis*, the lower pitcher plants usually were shorter, lower in upper circumference, and larger in the basal circumference compared to the upper pitcher plant. This larger basal size of the pitcher could contribute to their role in capturing the prey easily on the ground (Handayani & Hadiah, 2019). Eventhough the upper pitcher plant has little effectiveness on prey capture (Moran et al., 1999), they are more resistant to the wind blows because of their small size and light weight.

4.3.3.5 Peristome and Mouth

The peristome is part of the *Nepenthes* pitchers, the upper pitcher rim that plays important roles in trapping mechanism of the insects. Bohn and Federle (2004) described that the peristome has a consistent microstructure with smooth, overlapping radial ridges of epidermal cells that form a sequence of steps towards the pitcher within. The Field Emission Scanning Electron Microscopy (FESEM) observation in this study shows the general close up view structures of the peristome (Figure 4.12).

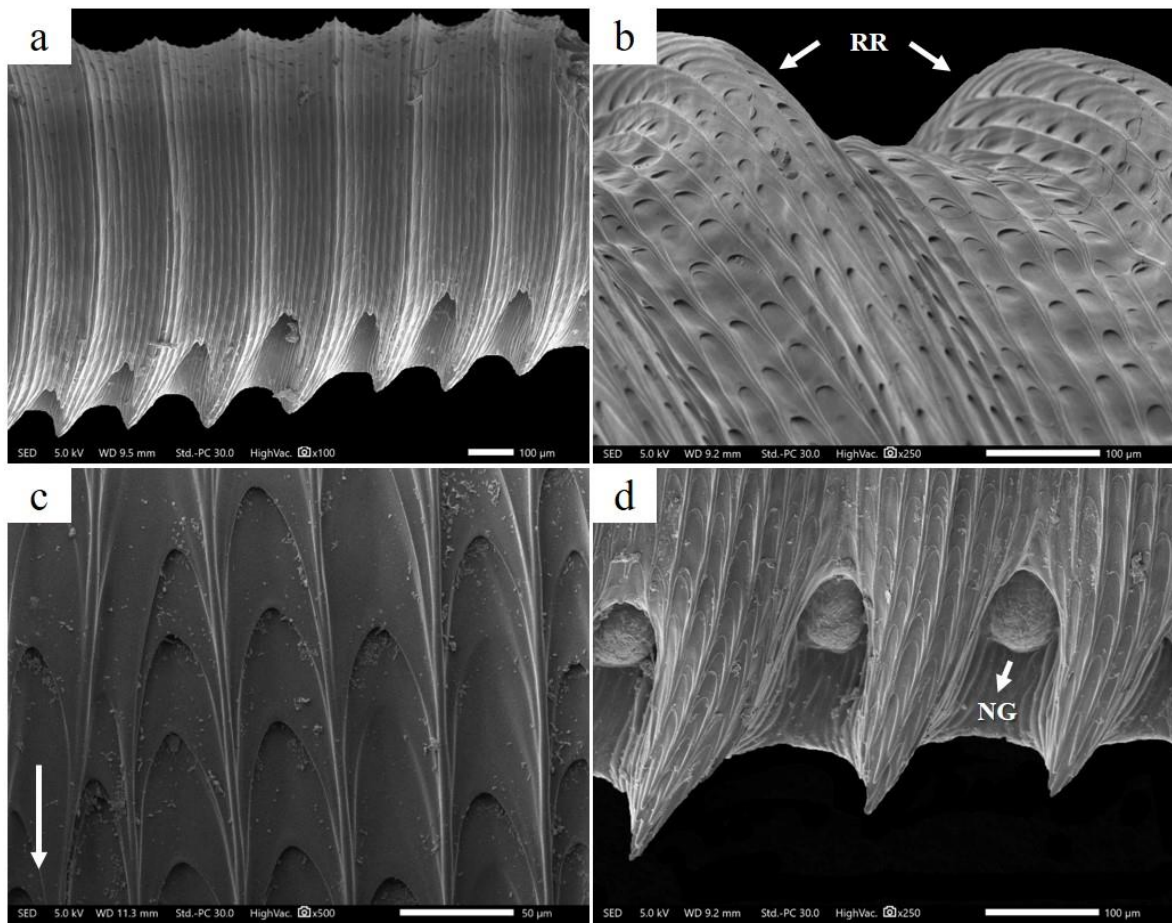


Figure 4.12: General peristome structure of *Nepenthes* studied (a) Inner edge of the peristome with teeth (b) radial ridges or ribs of peristome (c) the overlapping epidermal cells (d) tooth like projection with the nectar pores. RR = Radial Ridges, NG = Nectar Gland, Arrow = Direction towards the inner pitcher. Magnification a = x100, scale bar = 100 µm, b and d = x250, scale bar = 100 µm, c = x500, scale bar = 50 µm

Type of peristome

The peristome of the *Nepenthes* studied can be characterised morphologically into four types; cylindrical, subcylindrical, rounded, and flattened with the outer edge typically sinuate or entire, and the inner edge with teeth or lacking teeth.

Three taxa such as *Nepenthes albomarginata*, *N. gracilis*, and *N. reinwardtiana* possessed cylindrical peristome in section, while the other taxa, *N. hirsuta* has cylindrical to slightly flattened peristome, and *N. bicalcarata* has cylindrical peristome particularly at the

outer edge, and flattened at the inner edge. The subcylindrical peristome sometimes was observed in the upper pitcher plant of *Nepenthes rafflesiana*, and *N. nazreeana* sp. nov. ined., with slightly flattened towards the neck of the peristome. Meanwhile, the rounded peristome can be found in *Nepenthes hispida*, *N. northiana* (UP), and *N. tentaculata*

The flattened peristomes were observed in most of the taxa studied, *Nepenthes ampullaria*, *N. mirabilis*, *N. mirabilis* var. *echinostoma*, *N. northiana* (LP), *N. rafflesiana*, and *N. veitchii*. The peristome of *Nepenthes rafflesiana* also elongated into a long flattened neck, and the upper pitcher plant of this taxa developed distinctive raised section at the middle of the peristome of the frontal part.

Sizes of peristome

The smallest size of peristome in diameter was observed in a natural hybrid studied, *Nepenthes* x *trichocarpa* with c. 1.0 cm wide. Meanwhile, the biggest size peristome was observed in *N. northiana*, and *N. veitchii*, which they possessed flattened, and broad peristome with wavy outer edge.

Special features

Among the *Nepenthes* studied, *Nepenthes mirabilis* var. *echinostoma* also possessed a unique characteristic in its peristome. The ribs of the peristome are free and only attached at the base of outer edge, then, developing long peristome teeth. Other than that, *N. bicalcarata* developed two huge and sharply pointed peristome thorns at the apex, three to four times longer than the rest of the peristome. Both thorns were projecting downwards into the mouth of the pitcher. The sizes of the peristome thorns of the *N. bicalcarata* studied was

measured up to 2 cm long. Two theories were prevailed about the functions of the peristome thorns; (1) act as defence mechanism from the predatory animals (Burbidge, 1880), and (2) attracting and trapping prey mechanism (Clarke, 1993). A study by Marlis et al. (1999) revealed that these thorns consist of open giant nectar glands at the the apex of the thorn through observations in SEM (Figure 4.13).

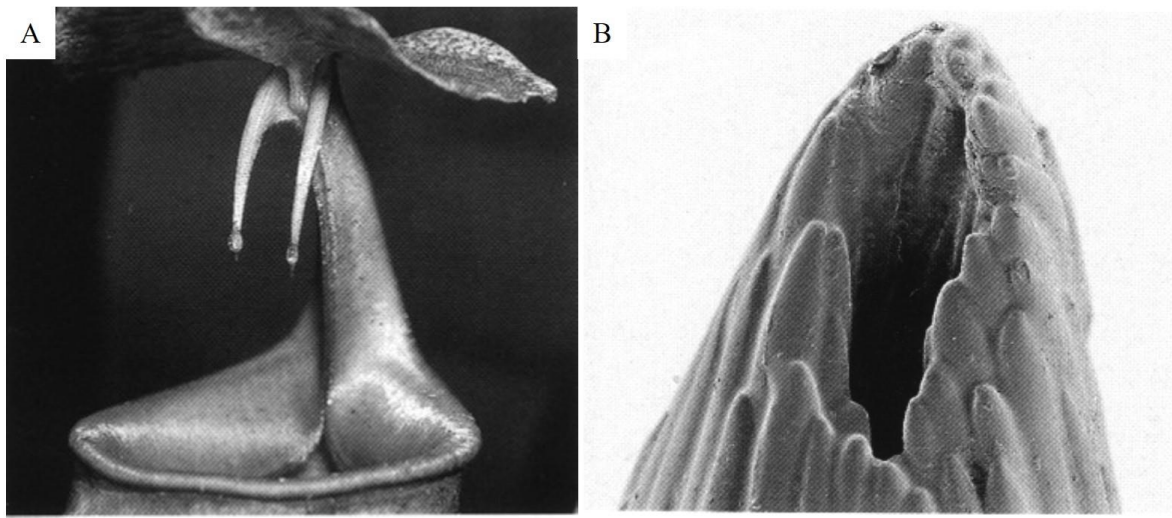


Figure 4.13: (A) Peristome thorns of *N. bicalcarata* (B) SEM images of apex of peristome thorn with opening of nectar duct in *Nepenthes bicalcarata* (taken from Marlis et al., 1999)

Mouth of pitcher

The mouth of the pitcher is the opening of the pitcher where the preys slip into the inner side of the pitcher from the peristome. The pitcher mouth shape of the *Nepenthes* studied are varied in shapes and sizes. The shapes were observed in several characteristics which are ovate, oval, suborbicular, concave, elliptic, oblique, rhombic.

The ovate shape was seen in most of the *Nepenthes* taxa studied such as *N. albomarginata*, *N. hirsuta*, *N. hispida*, *N. mirabilis*, *N. nazreeana* sp. nov. ined., *N. northiana*, *N. reinwardtiana*, *N. tentaculata*, and *N. veitchii*. They were observed whether in a narrow

or broadly ovate, oblique or concave. The mouth of *Nepenthes tentaculata* was also seen sinusoidal from its side view in its lower pitcher plant. *Nepenthes mirabilis* and its variety, *N. mirabilis* var. *echinostoma* also sometimes can be seen in elliptic shapes.

The oval mouth was observed only in a pitcher of detritivore taxon which is *Nepenthes ampullaria*, with almost horizontally. Its natural hybrids, *Nepenthes* x *hookeriana* and *N. x kuchingensis* have slightly similar mouth shapes as their parental plant, *N. ampullaria*. *Nepenthes bicalcarata* otherwise, possessed suborbicular mouth shape, with straight, almost horizontal at front, and rising abruptly at rear, forming a stout, vertical or overarching column. The remaining taxa, *Nepenthes gracilis*, and *N. rafflesiana* have a concave shape, with the later taxon was observed in oblique or horizontal mouth shape as well.

4.3.3.6 Lid of Pitchers

The lid of the pitchers in *Nepenthes* is also known as operculum, are developed and held above the mouth of the pitchers. Clarke (1997) thought that this feature plays important role in attracting and luring the prey, as well as to act as a roof from the rains from diluting the digestive fluids produced in the inner pitcher at the lower base. The examination of the lid morphology showed variety characteristics in shapes and sizes among the 18 *Nepenthes* taxa studied as shown in Table 4.5.

Table 4.5: Lid morphology of *Nepenthes* studied

<i>Nepenthes</i> taxa	Shape of Lid	Size of Lid		Apex	Base
		Length (cm)	Width (cm)		
<i>N. albomarginata</i>	Ovate	1.0 - 2.5	2.4-3.0	Rounded	Cuneate
<i>N. ampullaria</i>	Narrowly olanceolate	3.5-4.0	0.9-1.1	Rounded, slightly acute	Cuneate
<i>N. bicalcarata</i>	Broadly reniform	3.0-4.0	4.2-5.0	Rounded	Cordate
<i>N. gracilis</i>	Orbicular-ovate	0.5–3.0	2.15–3.0	Rounded	Cordate
<i>N. hirsuta</i>	Broadly to narrowly ovate or elliptic (LP)	3.5-5.0	3.0-5.0	Rounded	Shallowly cordate
	Ovate or ovate-oblong (UP)				
<i>N. hispida</i>	Ovate-elliptic	2.2–3.0	1.5-2.0	rounded	Truncate to slightly cordate
<i>N. mirabilis</i>	Elliptic, rarely orbicular	2.6-4.4	2.2-3.4	Rounded or slightly retuse	Rounded or truncate, very slightly vaulted, with 2 prominent veins.

Table 4.5 continued

<i>N. mirabilis echinostoma</i>	var.	Elliptic, rarely orbicular	3.8-8.0	3.2-3.5	Rounded or slightly retuse	Rounded or truncate, very slightly vaulted, with 2 prominent veins.
<i>N. nazreena</i>	sp. nov.	Ovate-suborbicular	4.5-6.0	3.0-5.4	Retuse-obcordate	Rounded-slightly cordate
<i>N. northiana</i>		Narrowly elliptic	3.0-13.5	1.0-5.5	Rounded	Cordate
<i>N. rafflesiana</i>		Orbicular, broadly or narrowly ovate to long elliptic (LP) Broadly or narrowly ovate, rarely orbicular, trapezoidal, elliptic or obovate. (UP)	6.7 – 7.7	6 – 9	Rounded, retuse, truncate, or slightly emarginate	Shallowly cordate or rounded Obtuse to slightly cordate
<i>N. reinwardtiana</i>		Ovate-shortly elliptic	2.3–3	1.7–2.3	Rounded	Truncate
<i>N. tentaculata</i>		Ovate (LP) Ovate or narrowly ovate-elliptical	1.0-4.4	0.8-2.0	Rounded or acute-rounded	Rounded or shallowly cordate
<i>N. veitchii</i>		Narrowly ovate-elliptic	2.8-6.0	1.5-4.0	Acute to rounded	Rounded, with asymmetrical appendage

Table 4.5 continued

<i>N. x bauensis</i>	Broadly elliptic – suborbicular	4.5-5.0	3.0-3.5	Subacute to rounded	Cuneate
<i>N. x hookeriana</i>	Narrowly ovate, slightly oblong	2.0-2.5	1.0-1.5	Rounded but slightly notched	Rounded-slightly cuneate
<i>N. x kuchingensis</i>	Oblanceolate	1.0–2.0	0.7–1.0	Rounded	Cuneate
<i>N. x trichocarpa</i>	Ovate-orbicular	1.2-2.0	1.0-1.4	Rounded	Cuneate

The lid of pitcher in the 18 *Nepenthes* studied show difference morphology in their shapes, apex, and bases. The shapes of the lid are mostly ovate, elliptic, orbicular or suborbicular, oblanceolate, obovate, oblong, and reniform. *Nepenthes bicalcarata* has reniform lid shape that looks broader in size rather than longer. The narrowly or broadly ovate lid shape was seen in several taxa such as *Nepenthes albomarginata*, *N. hirsuta*, *N. rafflesiana*, *N. tentaculata*, and *N. x hooekriana*. *Nepenthes ampullaria* possessed a small and narrowly oblanceolate lid shape that are reflexed or held away from the mouth of the pitcher. This shape also can be seen in its natural hybrid, *Nepenthes x kuchingensis*. The elliptic shape also was seen in the lids of other taxa, *N. mirabilis*, and its variety, *Nepenthes mirabilis* var. *echinostoma*, *N. northiana*, and sometimes in lower pitcher of *N. hirsuta* and the upper pitcher of *N. rafflesiana*. Meanwhile, the orbicular lid was noticed as well in the lower pitcher of *Nepenthes rafflesiana*.

Other taxa, forming intermediate characteristics between two shapes of lids; *Nepenthes gracilis* (orbicular to ovate), upper pitcher of *N. hirsuta* (ovate to oblong), *N. hispida* (ovate to elliptic), *N. nazreeana* sp. nov. ined. (ovate to suborbicular), *N. rafflesiana* (broadly or narrowly ovate to elliptic), *N. reinwardtiana* (ovate to shortly elliptic), the upper pitcher of *N. tentaculata* (narrowly ovate to elliptical), *N. veitchii* (ovate to elliptical), *N. x bauensis* (elliptic to suborbicular), and *N. x trichocarpa* (ovate to orbicular).

The apex of the lids was observed mostly developed in rounded shape in majority of the *Nepenthes* studied, except *N. nazreeana* sp. nov. ined, which forming retuse to obcordate lid shape. Meanwhile, the lid of natural hybrid of *Nepenthes x hookeriana* was a slightly notched in its rounded apex. *Nepenthes mirabilis* and its variety, *N. mirabilis* var. *echinostoma* have rounded or slightly retuse lid apex. *Nepenthes tentaculata* sometimes was observed having acute to rounded lid apex. This character also was seen in *Nepenthes*

veitchii. The limestone natural hybrid, *Nepenthes* x *bauensis* revealed subacute to rounded lid apex, meanwhile *N. rafflesiana* shows various type of lid apex other than rounded such as retuse, truncate, or slightly emarginated.

Several types of lid base were identified; cuneate, cordate, truncate, rounded, and obtuse. Sometimes, a taxon can possess more than one character of lid base. The cuneate lid bases were developed in *Nepenthes ampullaria*, and three natural hybrids studied, *N. x bauensis*, *N. x kuchingensis*, and *N. x trichocarpa*. The other hybrid, *Nepenthes* x *hookeriana* had rounded to slightly cuneate lid base. The cordate lid base was revealed in few taxa which included *Nepenthes bicalcarata*, *N. hirsuta*, *N. northiana*, *N. rafflesiana*, and *N. tentaculata*. *Nepenthes rafflesiana* was observed having rounded or obtuse lid base. The remaining taxa, *Nepenthes hispida*, *N. mirabilis*, *N. mirabilis* var. *echinostoma*, and *N. reinwardtiana* have a truncate lid base. These two taxa, *Nepenthes mirabilis* and *N. mirabilis* var. *echinostoma* also revealed a rounded lid base.

4.3.4 Type of Inflorescences

The inflorescences of *Nepenthes* are dioecious which grows in two forms which are staminate inflorescences and pistillate inflorescences. The structures of these two forms are distinguishable in different characters in which the staminate inflorescences bear male flower characteristics while pistillate inflorescences develop female flower characteristics. These inflorescences can grow either in racemose or panicle type (Figure 4.14) and emerge erect at the apex of the stem of mostly in upper pitcher plant. The structure of *Nepenthes* male flower is made up of tetrasporangiate anther head at the top of androphore, four sepal-like tepals, and pedicel attached to the peduncle. Meanwhile, the female flower is comprising of viscid stigma, sepal-like tepals, and pedicel (Figure 4.15).

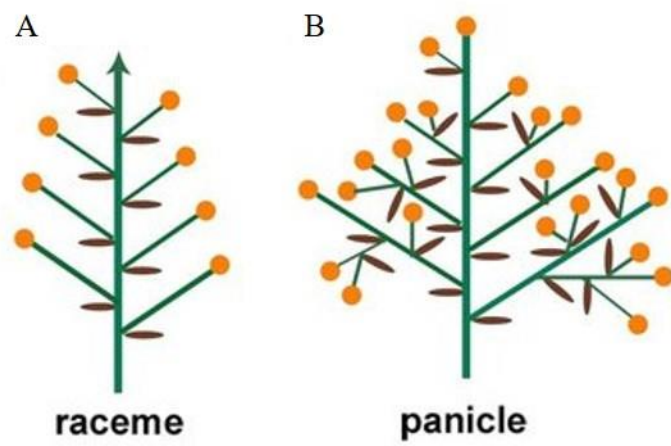


Figure 4.14: Diagram of type of inflorescences. (A) Raceme or racemose (B) Panicle (adapted from Yingying et al., 2014)

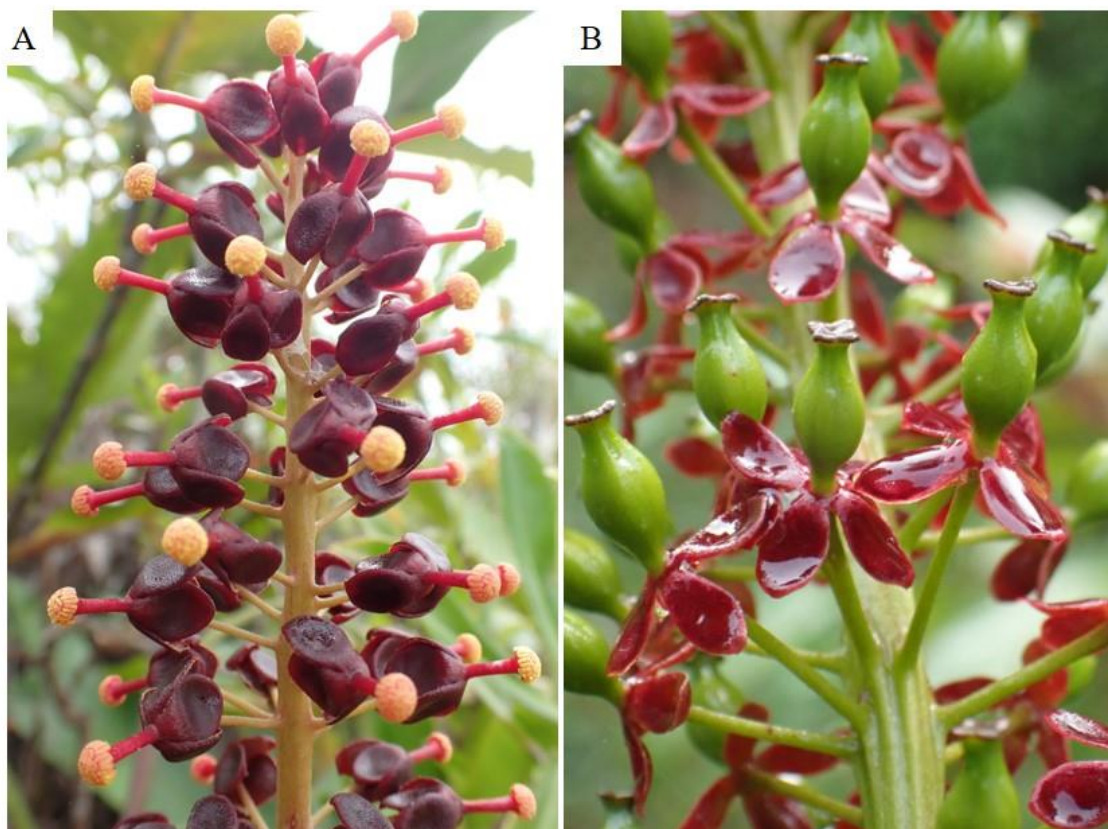


Figure 4.15: The inflorescences of *Nepenthes*. (A) Male flowers (B) Female flowers

The observations of inflorescences/infructescences of *Nepenthes* were made based on the collected specimens from the field (*N. albomarginata*, *N. ampullaria*, *N. gracilis*, *N. mirabilis*, *N. rafflesiana*, *N. reinwardtiana*, and *N. nazreeana* sp. nov. ined.) and SAR herbarium specimens (*N. bicalcarata*, *N. northiana*, *N. tentaculata*, and *N. veitchii*). The panicle type of inflorescence was observed in four taxa, *N. ampullaria*, *N. reinwardtiana*, *N. northiana*, and *N. veitchii*. Meanwhile, the remaining five taxa developed raceme or racemose inflorescences.

4.4 Anatomy

Thirteen *Nepenthes* taxa were selected for anatomical analysis viz. *N. albomarginata*, *N. ampullaria*, *N. gracilis*, *N. mirabilis*, *N. mirabilis* var. *echinostoma*, *N. nazreeana* sp. nov. ined., *N. rafflesiana*, *N. reinwardtiana*, *N. x hookeriana*, *N. x kuchingensis* and *N. x trichocarpa*. The observations were focused on the epidermal layers of leaves and the midrib.

4.4.1 Leaf Surface

4.4.1.1 Shape of Epidermal Cell and Type of Anticlinal Wall

Observations were made on the leaf surfaces of 13 selected *Nepenthes* taxa. The results show that the epidermal cell of *Nepenthes* studied on both surfaces is polygonal shapes. Furthermore, the patterns of anticlinal walls were observed in two types; straight or sinuous. Six *Nepenthes* taxa; *N. mirabilis*, *N. mirabilis* var. *echiostoma*, *N. nazreeana* sp. nov. ined., *N. rafflesiana*, *N. reinwardtiana* and *N. x hookeriana* display straight anticlinal wall on both surfaces; adaxial and abaxial of leaves (Figure 4.17). Meanwhile, *N. gracilis*, *N. hispida*, and *N. x kuchingensis* reveal sinuous anticlinal walls on both surfaces of leaves (Figure 4.18). The remaining four taxa, *N. albomarginata*, *N. ampullaria*, *N. hirsuta*, and *N. x trichocarpa* show a different type of anticlinal simultaneously on both surfaces which the sinuous on the abaxial, while, the straight on the adaxial (Figure 4.19).

4.4.1.2 Occurrence of Stomata and Stomatal Complex Type

Stomata predominantly occur in leaves and can be observed at the abaxial or/adaxial surfaces of leaves. There are three types of position or occurrence of stomata in the leaves which are known as hypostomatic leaf (stomata present on the abaxial surface only), amphistomatic leaf (stomata present on both surfaces of the abaxial and adaxial surface), and epistomatic leaf (stomata present on the adaxial surface only). Twelve *Nepenthes* taxa develop hypostomatic leaves which include *N. albomarginata*, *N. ampullaria*, *N. gracilis*, *N. mirabilis*, *N. nazreeana* sp. nov. ined., *N. rafflesiana*, *N. reinwardtiana*, *N. x hookeriana*, and *N. x trichocarpa*. The other taxon, *N. x kuchingensis* develops amphistomatic leaves with the stomata present on both surfaces of the leaves, but lack on the adaxial surface. (Table 4.6).

Table 4.6: Comparison of stomatal characteristics of 13 *Nepenthes* studied (Nabilah Huda et al., 2022)

<i>Nepenthes</i> taxa	Stomatal Complex Type	Mean of stomatal size on the abaxial (µm)		Mean of stomatal density on the abaxial (mm ⁻²)	
		Length	Width	Abaxial	Adaxial
<i>N. albomarginata</i>	Anomocytic	31.90	26.56	160.26	-
<i>N. ampullaria</i>	Anomocytic	30.00	24.19	216.35	-
<i>N. gracilis</i>	Anomocytic	26.34	21.54	208.33	-
<i>N. hirsuta</i>	Anomocytic	25.19	23.74	64.10	-
<i>N. hispida</i>	Anomocytic	31.08	24.19	104.17	-
<i>N. mirabilis</i>	Anomocytic	24.05	24.72	200.32	-
<i>N. mirabilis</i> var. <i>echinostoma</i>	Anomocytic	30.14	27.22	232.37	-
<i>N. nazreeana</i> sp. nov. ined.	Anomocytic	33.76	27.28	208.33	-
<i>N. rafflesiana</i>	Anomocytic	24.14	21.38	160.26	-
<i>N. reinwardtiana</i>	Anomocytic	32.23	30.69	96.15	-
<i>N. x hookeriana</i>	Anomocytic	32.16	22.07	488.78	-

Table 4.6 continued

<i>N. x trichocarpa</i>	Anomocytic	30.26	27.30	296.47	-
<i>N. x kuchingensis</i>	Anomocytic	23.87	21.26	80.13	24.04

The results also show that all 13 *Nepenthes* studied develop kidney-like shape stomata with a lack of subsidiary cells. This stomatal complex type is known as anomocytic or ranunculaceous (Figure 4.16). Metcalfe and Chalk (1950) described that this stomatal complex type has five or more subsidiary cells that are undistinguishable from the epidermal cells. The findings are consistent with previous research by Al Farishy et al. (2016) and Ghazalli et al. (2020; 2021). However, Rizqiani et al. (2018) discovered that *Nepenthes* does not always have anomocytic stomata, as *N. bicalcarata* has actinocytic stomata.

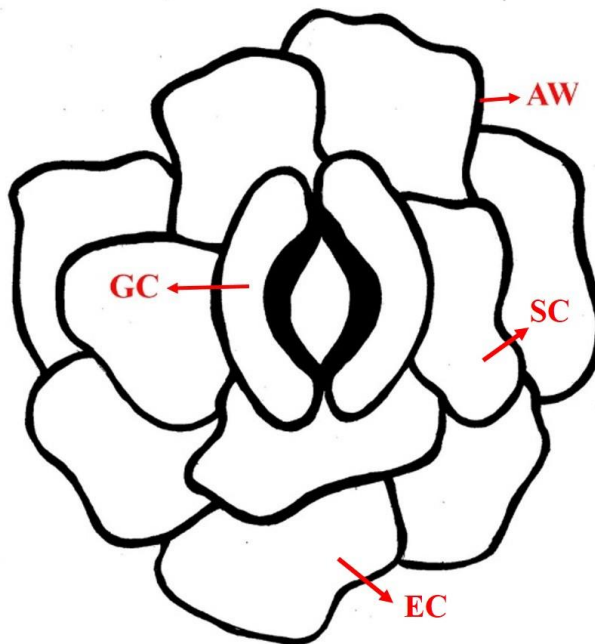


Figure 4.16: Illustration of anomocytic or ranunculaceous stomatal complex type. GC = Guard Cells, AW = Anticlinal Wall, SC = Subsidiary Cell, EC = Epidermal Cell.
Illustration by Nabilah Huda, M. H.

4.4.1.3 Stomatal Size and Stomatal Density

The stomatal sizes of *Nepenthes* studied were measured in μm , the length of the stomata multiply by the width of the stomata. The shortest length of stomata was observed on the abaxial surface of *N. x kuchingensis* with an average of 23.87 μm , followed by *N. mirabilis* (24.05 μm), and *N. rafflesiana* (24.14 μm) respectively. Whereas the longest length of stomata was observed in *N. nazreeana* sp. nov. ined. with an average, of 33.76 μm , followed by several taxa such as *N. reinwardtiana* (32.23 μm), *N. albomarginata* (31.90 μm), and *N. hispida* (31.08 μm).

The stomatal density of the *Nepenthes* studied was measured as well. The number of stomata per unit area of the leaves varied among the taxa. The highest density of stomata was seen in a natural hybrid, *N. x hookeriana* with an average of 64.10 mm^{-2} on its abaxial surface, while the lowest stomatal density was observed in the Bornean endemic, *N. hirsuta* with an average of 64.10 mm^{-2} . The sole taxon with stomata presence on the adaxial, *N. x kuchingensis* revealed a stomatal density with an average of 24.04 mm^{-2} . Based on the findings, the 13 *Nepenthes* studied are classified into four informal groups as in Table 4.7; **Group 1** (Stomatal density $\leq 100 \text{ mm}^{-2}$), **Group 2** (Stomatal Density $101 \leq 200 \text{ mm}^{-2}$), **Group 3** (Stomatal Density $201 \leq 300 \text{ mm}^{-2}$), and **Group 4** (Stomatal Density ≥ 301).

Table 4.7: Informal classification of 13 *Nepenthes* studied based on the stomatal density

Group 1 (Stomatal density ≤ 100 mm^{-2})	Group 2 (Stomatal Density $101 \leq 200$ mm^{-2})	Group 3 (Stomatal Density $201 \leq 300 \text{ mm}^{-2}$),	Group 4 (Stomatal Density ≥ 301 mm^{-2})
<i>N. hirsuta</i>	<i>N. albomarginata</i>	<i>N. ampullaria</i>	<i>N. x hookeriana</i>
<i>N. reinwardtiana</i>	<i>N. mirabilis</i>	<i>N. gracilis</i>	
<i>N. x kuchingensis</i>	<i>N. rafflesiana</i>	<i>N. mirabilis</i> var. <i>echinostoma</i>	
	<i>N. hispida</i>	<i>N. nazreeana</i> sp. nov. ined.	
		<i>N. x trichocarpa</i>	

4.4.1.4 Glandular Structures

Glandular structures are developed from the epidermis of the leaves and they secrete various secondary plant products or compounds to attract insects or as a defense mechanism (Cutler et al., 2007; Crang et al., 2018). The *Nepenthes* studied exhibit glandular structures on the adaxial and abaxial surfaces of leaves among the polygonal epidermal cells. These structures are conspicuous and known as sessile glands which were found in two types which are orbicular and irregular flower-like shapes. The abaxial and adaxial epidermis of 13 *Nepenthes* studied were included herein for reference (Figure 4.17, Figure 4.18, & Figure 4.19).

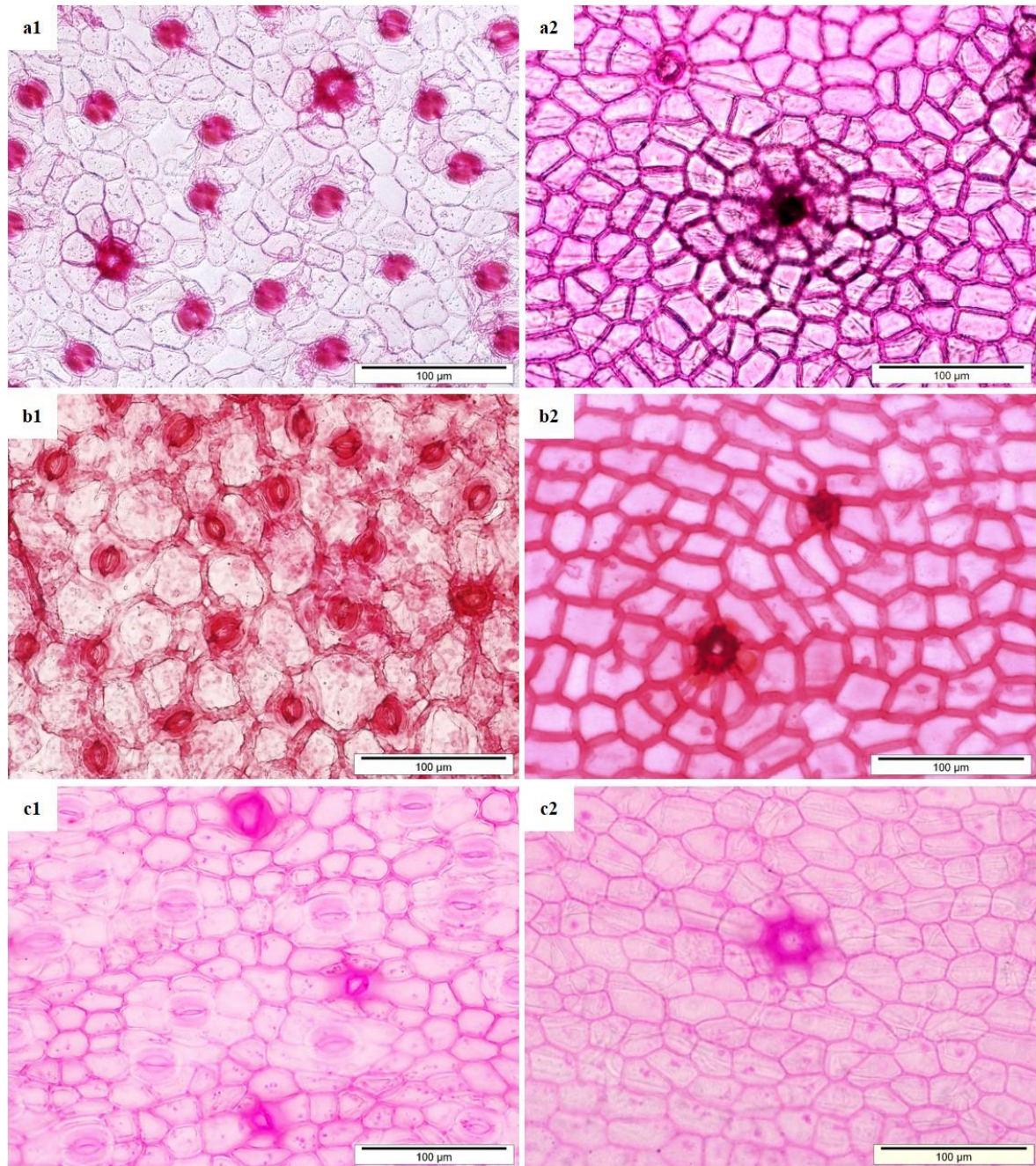


Figure 4.17: Straight anticlinal walls on the abaxial (a1-f1), and adaxial surfaces (a2-f2) of leaves in *Nepenthes* studied. (a) *N. mirabilis* (b) *N. mirabilis* var. *echinostoma* (c) *N. nazreeana* sp. nov. ined. (d) *N. rafflesiana* (e) *N. reinwardtiana* (f) *N. x hookeriana*. Magnification 400×, scale bar = 100 μm

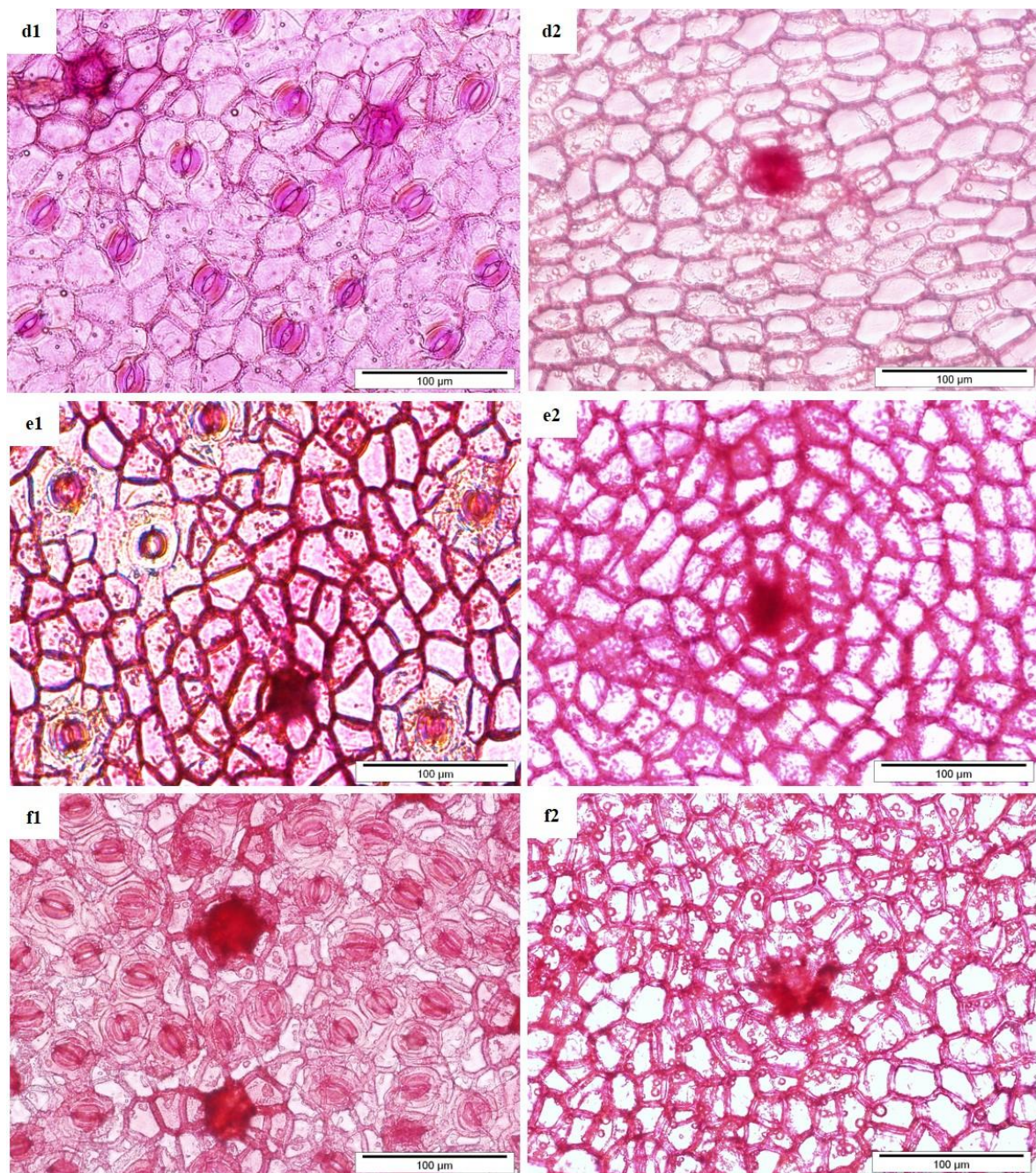


Figure 4.17 continued. (d) *N. rafflesiana* (e) *N. reinwardtiana* (f) *N. x hookeriana*. Magnification 400×, scale bar = 100 µm

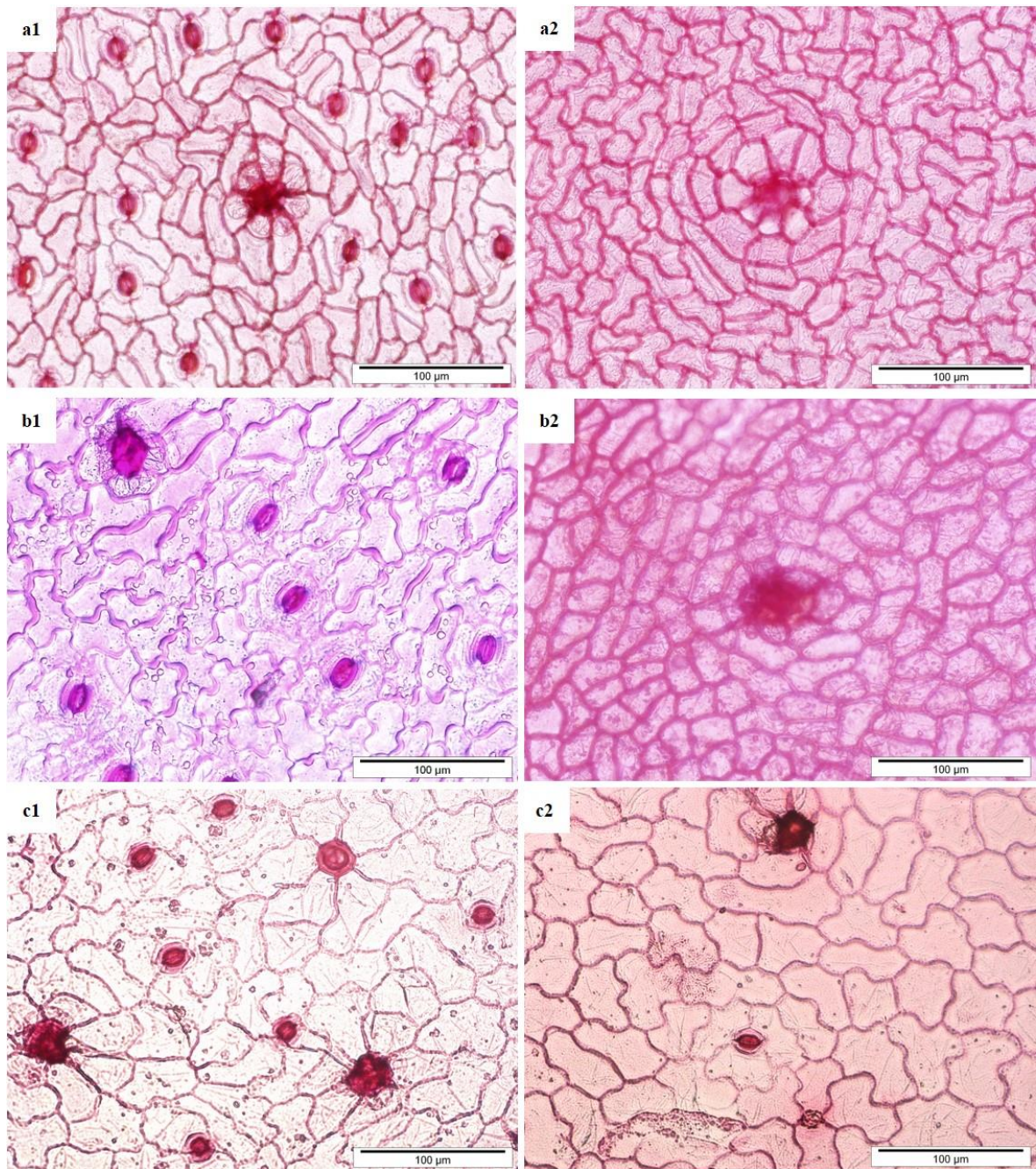


Figure 4.18: Sinuous anticlinal walls on the abaxial (a1-c1), and adaxial surfaces (a2-c2) of leaves in *Nepenthes* studied. (a) *N. gracilis* (b) *N. hispida* (c) *N. x kuchingensis*. Magnification 400×, scale bar = 100 μm

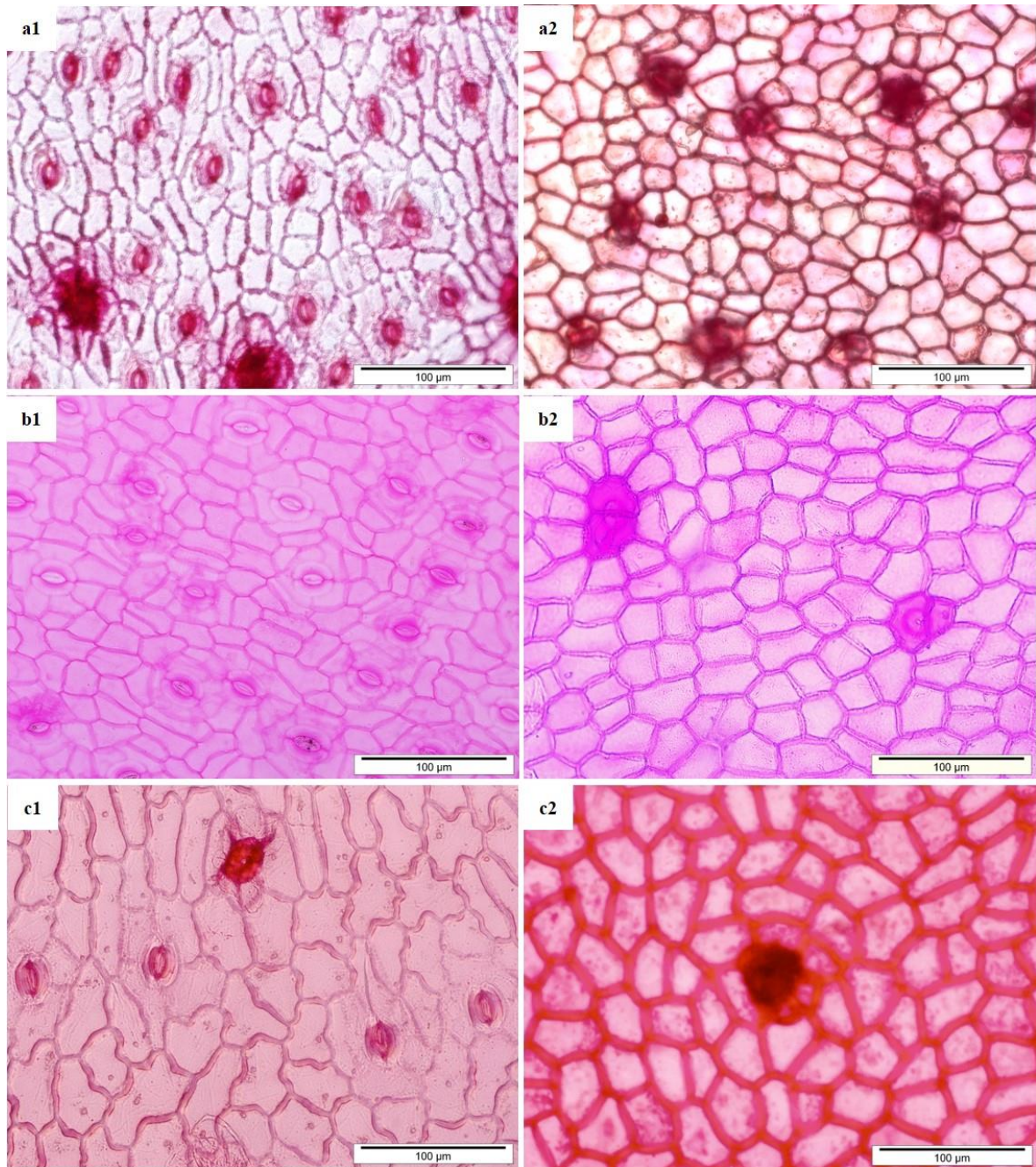


Figure 4.19: Sinuous anticlinal walls on the abaxial (a1-c1), and straight anticlinal walls on the adaxial surfaces (a2-c2) of leaves in *Nepenthes* studied. (a) *N. albomarginata* (b) *N. ampullaria* (c) *N. hirsuta*. Magnification 400×, scale bar = 100 µm

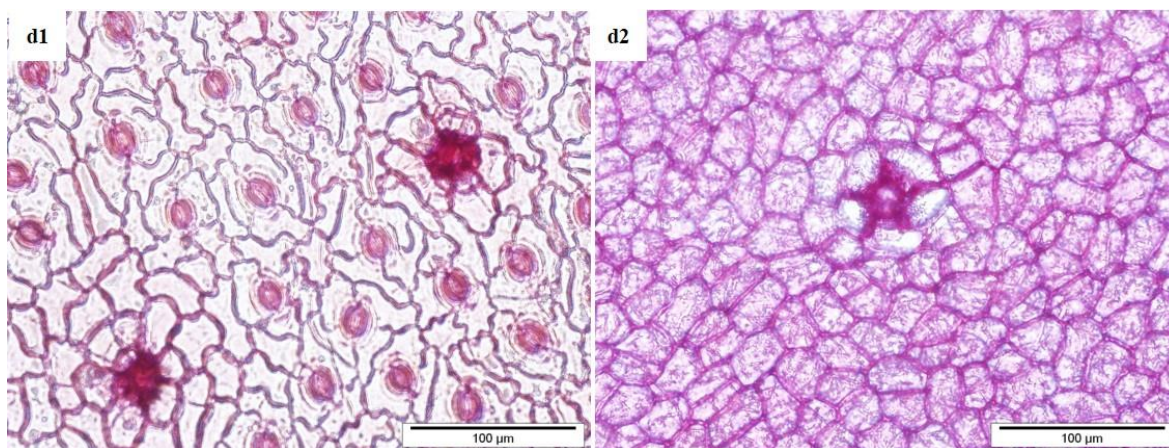


Figure 4.19 continued. (d) *N. x trichocarpa*. Magnification 400×, scale bar = 100 μm

4.4.2 Midrib

Midrib is a central vein of the leaves from the apex to the base that provides mechanical and chemical support to the leaves. The anatomical characteristics of the midrib such as the midrib shape, type of vascular bundle system, vascular bundle arrangements, and others have a taxonomic value that can be used to identify and discriminate the *Nepenthes* taxa.

4.4.2.1 Midrib Outer Shape

The shape of the midrib of the *Nepenthes* studied was analysed based on the midrib outline on the adaxial and abaxial surfaces. The outlines on the adaxial were described as slightly flattened, slightly concave, U-shape, or V-shaped. Meanwhile, the abaxial outlines were described as UV-shaped, prominent V-shaped, or arch-shaped. These shapes were arranged and categorised into four types based on the observations of the midrib in the *Nepenthes* studied (Figure 4.21).

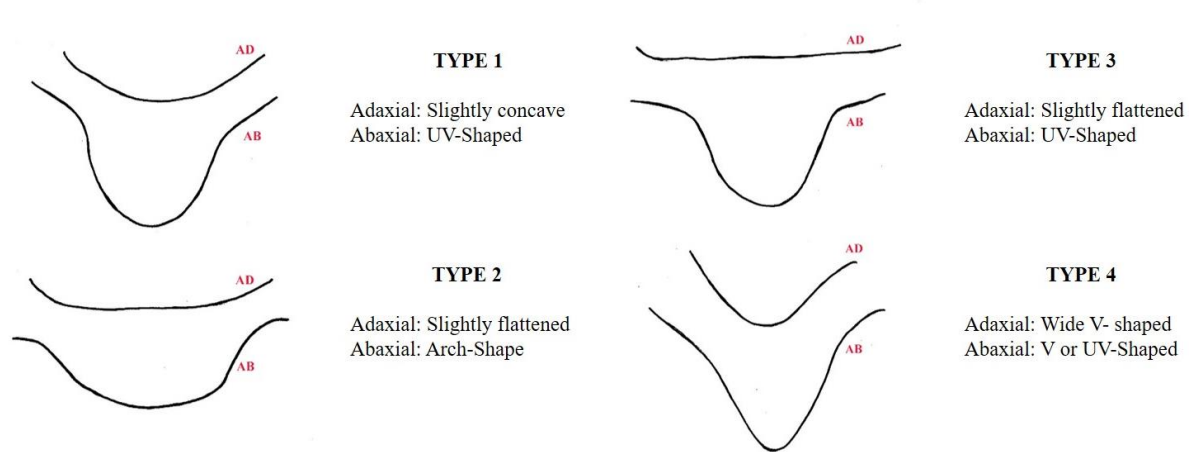


Figure 4.20: Type of midrib outer shape in selected 13 *Nepenthes* studied. AD = Adaxial surface, AB = Abaxial surface

The majority of the *Nepenthes* studied are classified as Type 1 which includes eight taxa; *N. hirsuta*, *N. hispida*, *N. mirabilis*, *N. mirabilis* var. *echinostoma*, *N. nazreeana* sp. nov. ined., *N. rafflesiana*, *N. x kuchingensis* and *N. x trichocarpa*. Type 2 which is characterised as slightly flattened on the adaxial and arch-shaped on the abaxial was found in *Nepenthes ampullaria* only. The other three taxa, such as *Nepenthes reinwardtiana*, and *N. x kuchingensis* own the midrib outer shape Type 3, with their adaxial outliner formed slightly flattened, and formed in UV-shaped on the abaxial. Meanwhile, Type 4 was noticed in *Nepenthes gracilis* only.

4.4.2.2 Vascular Bundles

The vascular bundle is part of the transport system in vascular plants that are composed of the xylem, phloem, and sometimes cambium (Cutler, 1978; Cutler, 2008). The observation revealed that all 13 *Nepenthes* studied have a consistent closed, collateral type of vascular bundles in all selected 13 taxa (Figure 4.22). The vascular bundles were noticed

in elliptical to oval shapes. The vascular bundle arrangements of each taxon in *Nepenthes* were described (Table 4.8).

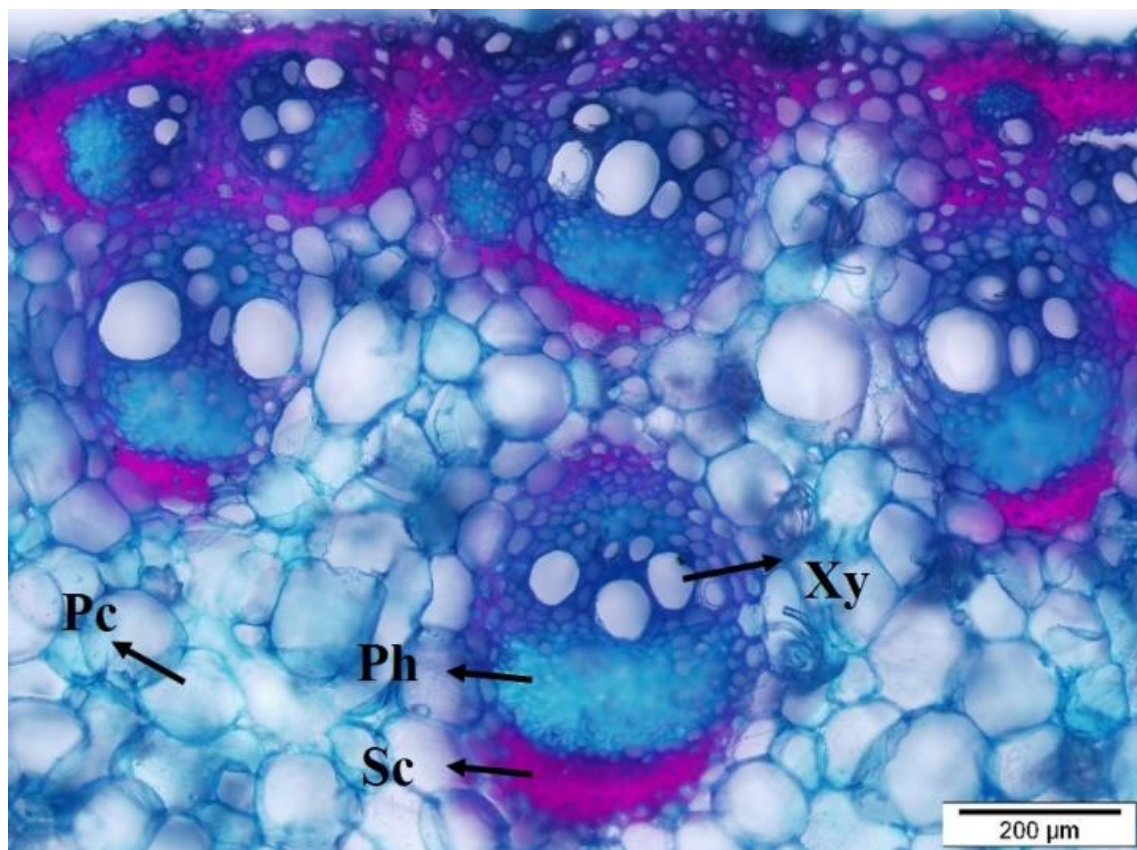


Figure 4.21: Characteristics of vascular bundle in *Nepenthes* studied. Pc = Parenchyma Cell, Ph = Phloem, Sc = Sclerenchyma, Xy = Xylem. Magnification = 200x, Scale Bar = 200 µm

Table 4.8: Vascular bundles arrangement in selected 13 *Nepenthes* taxa studied in western Sarawak

<i>Nepenthes</i> Taxa	Vascular Bundle Arrangement			
	Outer Ring	Main VB	Medullary VB	Additional VB
<i>N. albomarginata</i>	Circular	7VB	1-3 scattered VB	Absent
<i>N. ampullaria</i>	Elliptical	13VB	1-3 scattered VB	Present, Smaller size VB at the outer ring near the adaxial
<i>N. gracilis</i>	Rounded	6 VB	1-3 scattered VB	Absent
<i>N. hirsuta</i>	Rectangular	8VB	1-3 scattered VB	Present, smaller size VB at the outer ring near the adaxial
<i>N. hispida</i>	Rounded	7 – 8 VB	1-3 scattered VB	Absent
<i>N. mirabilis</i>	Rounded	8VB	1-3 scattered VB	Present, smaller size VB at the outer ring near the adaxial
<i>N. mirabilis</i> var. <i>echinostoma</i>	Triangular	13VB	1-3 scattered VB	Present, smaller size VB at the outer ring near the adaxial
<i>N. nazreeana</i> sp. nov. ined.	Triangular	17VB	1-3 scattered VB	Absent
<i>N. rafflesiana</i>	Triangular	17VB	1-3 scattered VB	Absent
<i>N. reinwardtiana</i>	Circular	7VB	1-3 scattered VB	Absent
<i>N. x hookeriana</i>	Circular	14 VB	1-3 scattered VB	2VB present at the outer ring near the adaxial.
<i>N. x kuchingensis</i>	Rectangular	10VB	1-3 scattered VB	2VB present at the outer ring near the adax
<i>N. x trichocarpa</i>	Circular	11VB	1-3 scattered VB	Absent

VB = Vascular Bundle

The 13 *Nepenthes* studied have a complex vascular system, with a closed ring system made up of main vascular bundles capped by the sclerenchyma cell in four basic shapes; circular, elliptical, square to rectangular, and triangular (Figure 4.22). Most of the taxa are forming a circular outer ring, namely *N. albomarginata*, *N. reinwardtiana*, *N. x trichocarpa*, and *N. x hookeriana*. Meanwhile, three taxa form rounded outer ring shapes which are *N. gracilis*, *N. hispida*, and *N. mirabilis*. The other taxa such as *N. hirsuta*, and *N. x kuchingensis* revealed a slightly square to a rectangular shape. Whereas, *N. ampullaria* exhibit an elliptical ring shape, and the remaining three taxa; *N. mirabilis* var. *echinostoma*, *N. nazreeana* sp. nov. ined. and *N. rafflesiana* shows a triangular outer ring shape.

They also have one to three medullary vascular bundles that are scattered at the centre of the midrib. Also, additional vascular bundles were observed at the outer edge of the ring, which frequently appeared in smaller sizes near the adaxial surface in a few taxa such as *N. ampullaria*, *N. hirsuta*, *N. mirabilis*, *N. mirabilis* var. *echinostoma*, *N. x hookeriana*, as well as *N. x kuchingensis*. In the remaining taxa, no additional vascular bundles were found.

Furthermore, the average number of vascular bundles present in each *Nepenthes* studied differs (Table 4.8). The highest average number of main vascular bundles in the midrib was found in two taxa known as *N. nazreeana* sp. nov. ined. and *N. rafflesiana*, with 17 VB, while the lowest average number main of vascular bundles was found in *N. gracilis* with 6 VB.

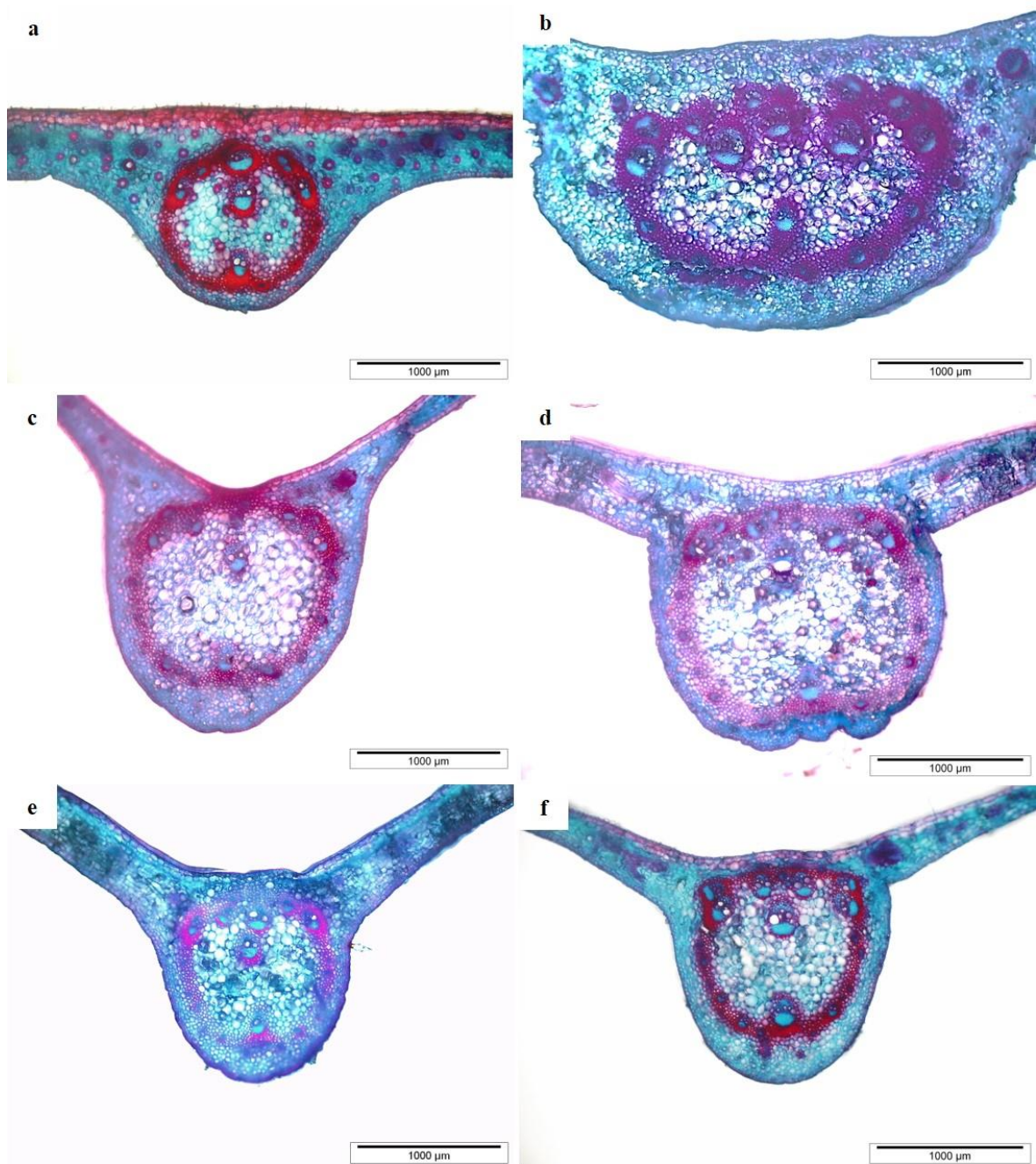


Figure 4.22: Transverse section of midribs of 13 *Nepenthes* studied shows a complex vascular system, with a closed ring system (a) *N. albomarginata* (b) *N. ampullaria*, (c) *N. gracilis* (d) *N. hirsuta* (e) *N. hispida* (f) *N. mirabilis*
Magnification = 40x, Scale bar = 1000 µm

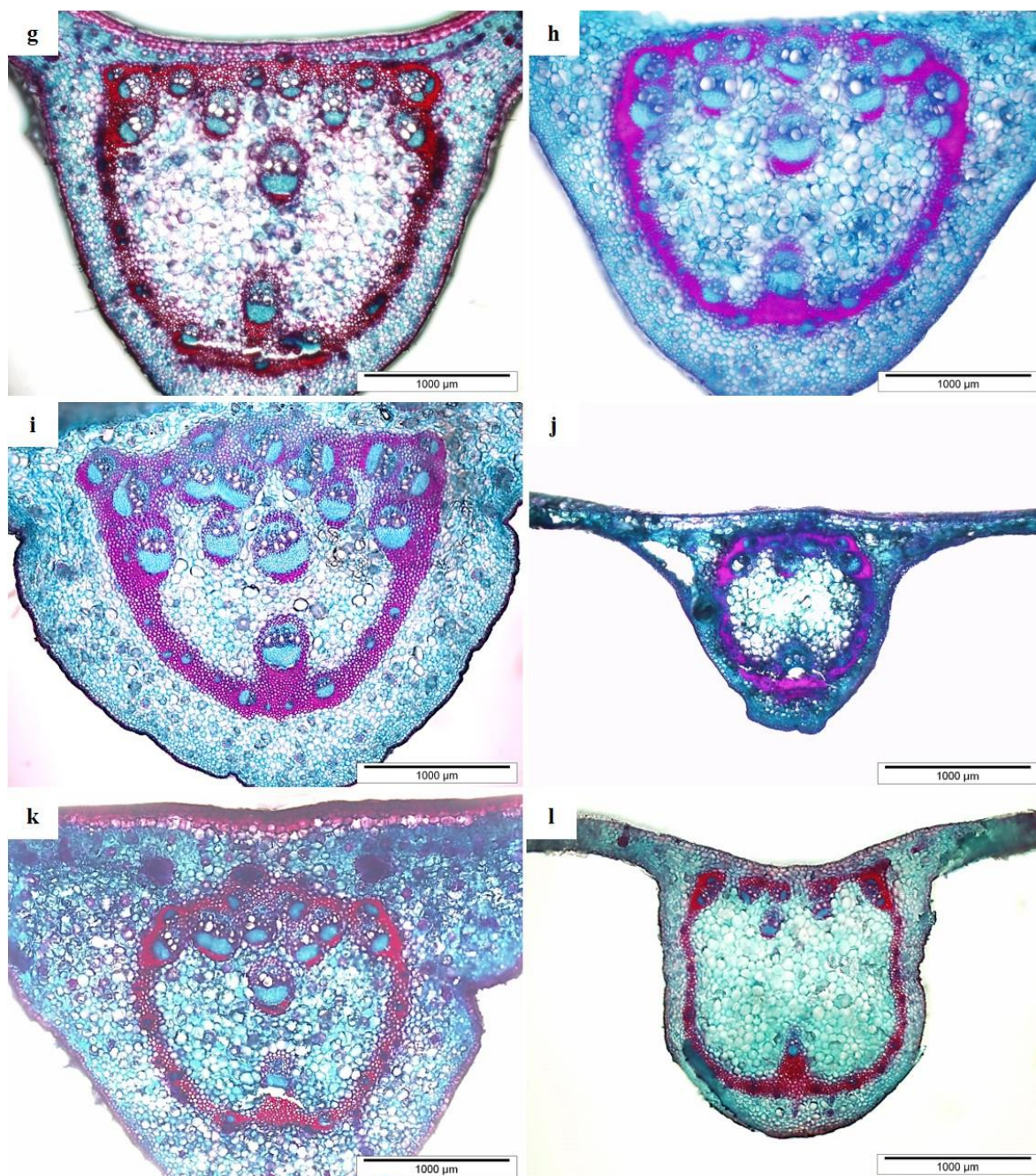


Figure 4.22 continued. (g) *N. mirabilis* var. *echinostoma* (h) *N. nazreeana*, sp. nov. ined. (i) *N. rafflesiana* (j) *N. reinwardtiana*, (k) *N. x hookeriana* (l) *N. x kuchingensis* (m) *N. x trichocarpa*. Magnification = 40x, Scale bar = 1000 µm

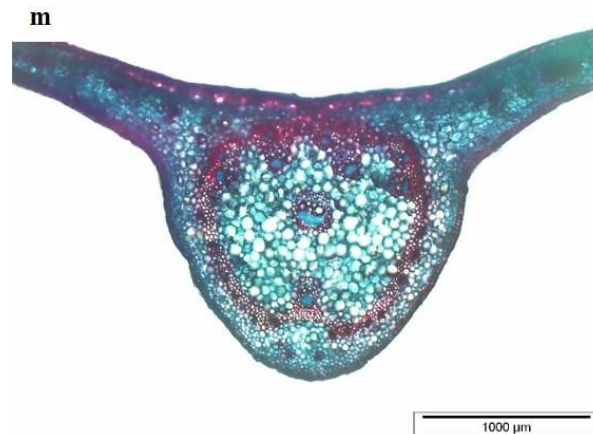


Figure 4.22 continued. (m) *N. x trichocarpa*. Magnification = 40x, Scale bar = 1000 μm

4.5 Micromorphology

The micromorphology of the leaves epidermis nowadays is considered important as it provides some significant taxonomic characteristics. Micromorphological characteristics are one of the modern taxonomic parameters that are commonly used in providing data to support the classical morphological data and to solve the taxonomic problems that arise in the plant groups (Yigit, 2016). The author also added that the micromorphology of plants can be analyzed from the leaf surface layer, stomata, trichomes, glandular hairs, and pollen structures by using Scanning Electron Microscopy (SEM). In this study, thirteen *Nepenthes* taxa collected from the field were included for analysis; *N. albomarginata*, *N. ampullaria*, *N. gracilis*, *N. hirsuta*, *N. hispida*, *N. mirabilis*, *N. mirabilis* var. *echinostoma*, *N. nazreeana* sp. nov. ined., *N. rafflesiana*, *N. reinwardtiana*, *N. x hookeriana*, *N. x kuchingensis*, and *N. x trichocarpa*. Several micromorphological characteristics of the *Nepenthes* were observed and identified, viz., trichomes, stomata, glands, and pollens structures to diagnose the significance of these characteristics in delimitating the species in this genus.

4.5.1 Stomata Formation

The formation of stomata in the anatomical study was inconspicuous. Hence, the epidermal layer of the *Nepenthes* leaves was observed further via Field Emission Scanning Electron Microscopy (FESEM) to analyse the micromorphological characteristics of the stomata. Three formations of stomata were identified in the *Nepenthes* taxa; raised stomata, semi-raised stomata, and sunken stomata (Figure 4.23).

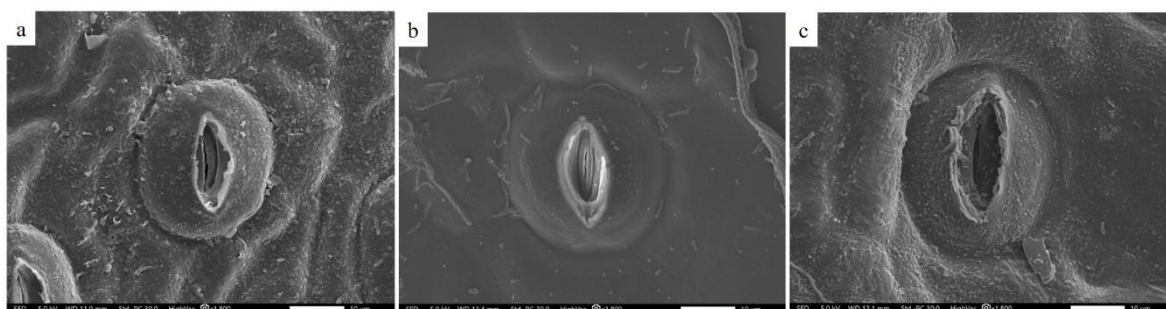


Figure 4.23: Stomata formation of the *Nepenthes* studied at the lamina surfaces. (a) Raised stomata (b) Semi-raised stomata (c) Sunken stomata. Magnification = x1800

The raised stomata were revealed on the abaxial surfaces of eight taxa, *Nepenthes albomarginata*, *N. ampullaria*, *N. mirabilis*, *N. mirabilis* var. *echinostoma*, *N. reinwardtiana*, *N. x trichocarpa*, *N. x hookeriana*, and *N. x kuchingensis*. Four taxa which include *N. gracilis*, *N. hirsuta*, *N. hispida*, and *N. nazreeana* sp. nov. ined. have semi-raised stomata, which the guard cells were formed at the same level as the epidermal cells on their leaf surfaces. Only one taxon, *N. rafflesiana* develops a sunken stomata formation.

4.5.2 Trichomes

Trichomes, which derived from the Greek word, *trikhoma* (hair) is a hair or hair-like growth or unicellular or multicellular epidermal appendages from the plant surfaces (Harris & Harris, 1994; Oksanen, 2018; Watts & Kariyat, 2021). This structure acts as a defense mechanism against abiotic and biotic stressors, for instance, UV rays, temperature,

extremities, and herbivores (Watts & Kariyat, 2018). The trichomes in all 13 *Nepenthes* taxa studied were observed mostly on leaf surfaces at the adaxial, and abaxial. They can be classified into two types which are glandular trichomes, and non-glandular trichomes. (Figure 4.23).

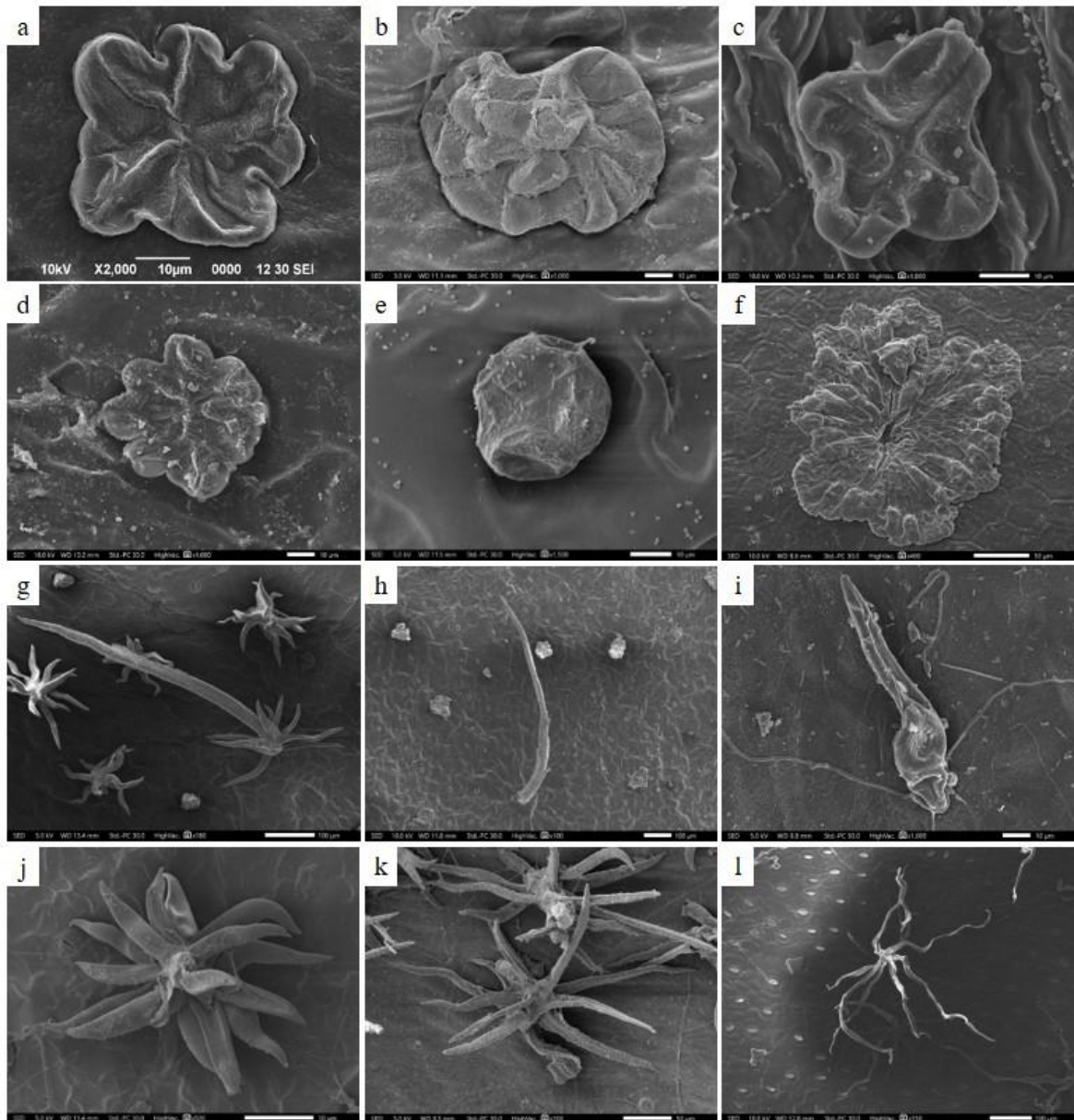


Figure 4.24: Type of trichomes of 13 *Nepenthes* studied in western Sarawak. (a-d) variation of peltate glandular trichomes (e) capitate glandular trichome (f) scale trichome (g) long simple, unicellular trichome with smooth surface, branched at the base (h) simple, long unicellular trichome with scale surface (i) Simple, short unicellular trichome, with smooth surface (j-l) variation of stellate rotate trichomes. Magnification a-l = x100 – x2000

The glandular trichomes of *Nepenthes* studied are comprised of peltate glandular trichomes, and capitate glandular trichomes. The peltate glandular trichomes were revealed in all 13 *Nepenthes* studied on the abaxial and adaxial surfaces of the lamina. These trichomes are developed in multicellular with four to eight cells. The capitate glandular trichomes also were observed in the *Nepenthes* studied particularly in *N. albomarginata*. These trichomes have a short stalk and round head containing metabolic products.

The non-glandular trichomes of *Nepenthes* studied comprise several types which are scale trichomes, short or long stellate rotate trichomes, simple unicellular with smooth or scale on surface and/or branched at the base. The scale trichomes were observed on the adaxial surface of leaves in *Nepenthes hirsuta*, *N. hispida*, and *N. nazreeana* sp. nov. ined. The stellate rotate trichomes were observed in most of the taxa on the abaxial surfaces such as *Nepenthes ampullaria*, *N. mirabilis*, *N. mirabilis* var. *echinostoma*, *N. nazreea* sp. nov. ined., *N. rafflesiana*, *N. x hookeriana*, and *N. x kuchingensis*. Also, the presence of this type of trichomes were seen on the lamina adaxial surfaces in *Nepenthes albomarginata* only. The micromorphological characteristic of trichomes on both surfaces of *Nepenthes* leaves were described in Table 4.9.

The short simple unicellular trichomes with smooth surfaces appeared in *N. mirabilis* but were seldom found on its surface. *Nepenthes ampullaria* portrayed long simple, unicellular trichomes with smooth surfaces, and branched at the base. Other taxa such as *N. hirsuta*, and *N. hispida* exhibit simple, unicellular trichomes with scale surfaces. The SEM of the adaxial and abaxial surfaces of the leaves of the *Nepenthes* studied as shown in Figure 4.25.

Table 4.9: Micromorphological characteristics of trichomes distributed on *Nepenthes* leaves

<i>Nepenthes</i> Taxa	Type of trichomes	
	Abaxial	Adaxial
<i>N. albomarginata</i>	Peltate glandular trichome	Capitate glandular Stellate rotate trichome Peltate glandular trichome
<i>N. ampullaria</i>	Stellate rotate trichome Peltate Glandular Simple unicellular trichome, branched at the base.	Peltate Glandular
<i>N. gracilis</i>	Peltate glandular trichome	Peltate glandular trichome
<i>N. hirsuta</i>	Peltate Glandular Long simple unicellular trichome, scale on the surface	Scale Trichome
<i>N. hispida</i>	Peltate Glandular Simple unicellular, branched	Scale Trichome
<i>N. mirabilis</i>	Peltate Glandular Stellate rotate trichome	Peltate Glandular
<i>N. mirabilis</i> var. <i>echinostoma</i>	Peltate glandular trichome Long stellate rotate trichome	Peltate glandular trichome

Table 4.9 continued

<i>N. nazreeana</i> sp. nov. ined	Long Stellate Rotate	Scale Trichome
	Peltate Glandular	Peltate glandular trichome
<i>N. rafflesiana</i>	Peltate glandular trichome	Peltate glandular trichome
	Long stellate rotate trichome	
<i>N. reinwardtiana</i>	Peltate glandular trichome	Peltate glandular trichome
<i>N. x hookeriana</i>	Stellate rotate trichome	Peltate glandular trichome
	Peltate glandular trichome	
<i>N. x kuchingensis</i>	Peltate glandular trichome	Peltate glandular trichome
	Stellate rotate trichome	
<i>N. x trichocarpa</i>	Peltate glandular trichome	Peltate glandular trichome

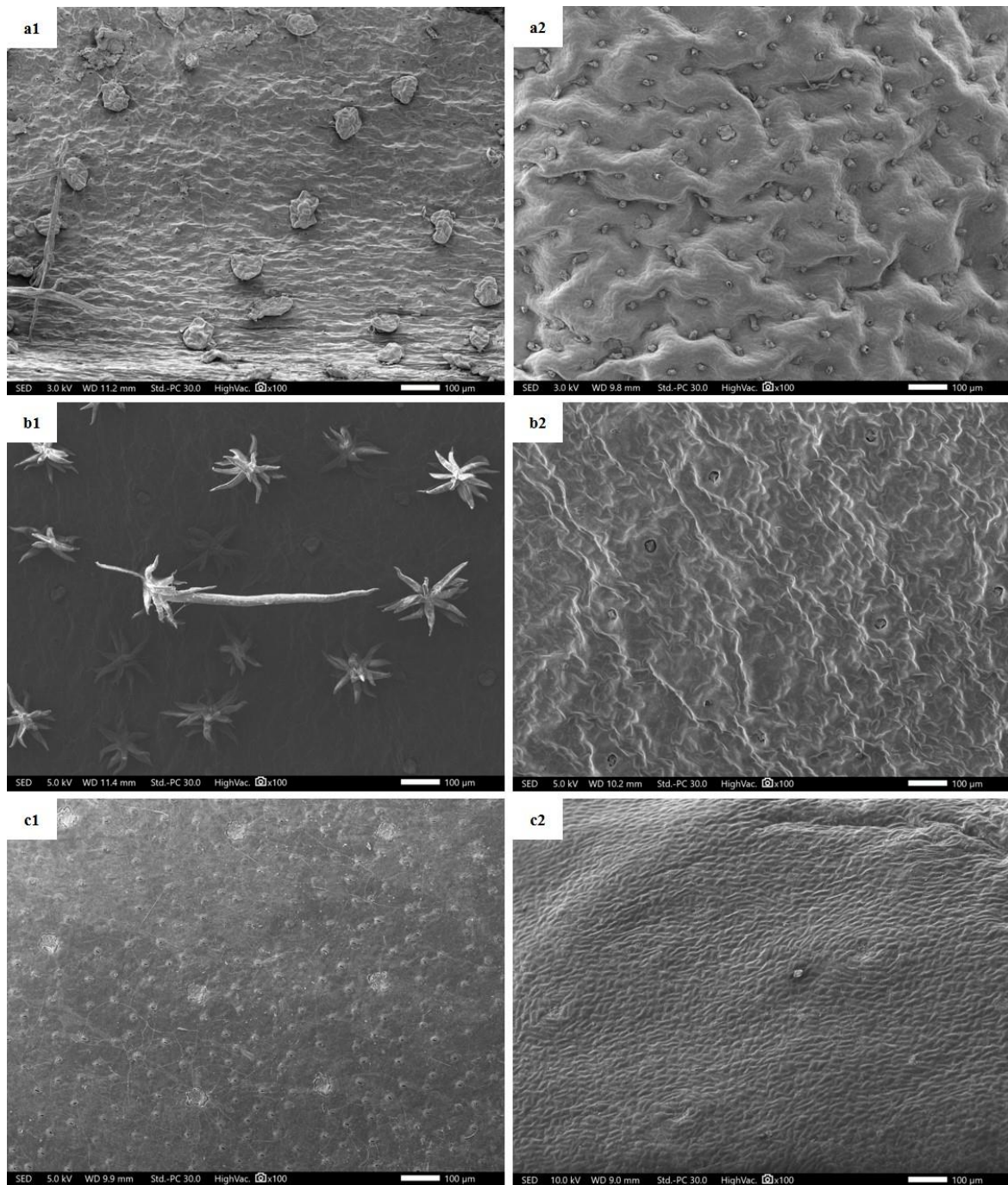


Figure 4.25: FESEM of abaxial and adaxial surfaces of leaves in *Nepenthes* studied. (a) *N. albomarginata* (b) *N. ampullaria* (c) *N. gracilis*. a1-c1 (Abaxial), b2-c3 (Adaxial). Magnification a-c = x100, scale bar = 100 µm

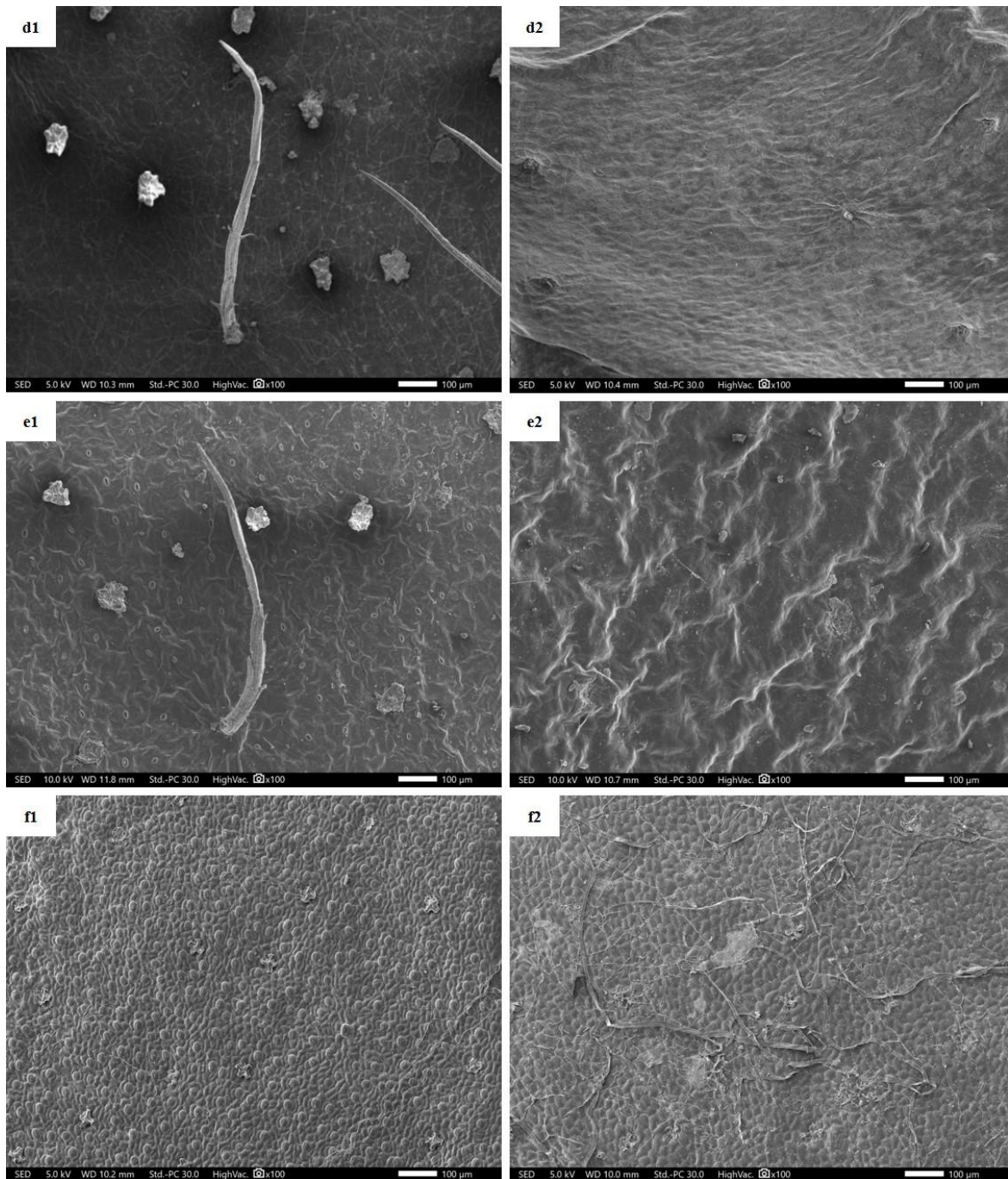


Figure 4.25 continued. (d) *N. hirsuta* (e) *N. hispida* (f) *N. mirabilis*. d1-f1 (Abaxial), d2-f3 (Adaxial). Magnification of d-f = x100, scale bar = 100 μm

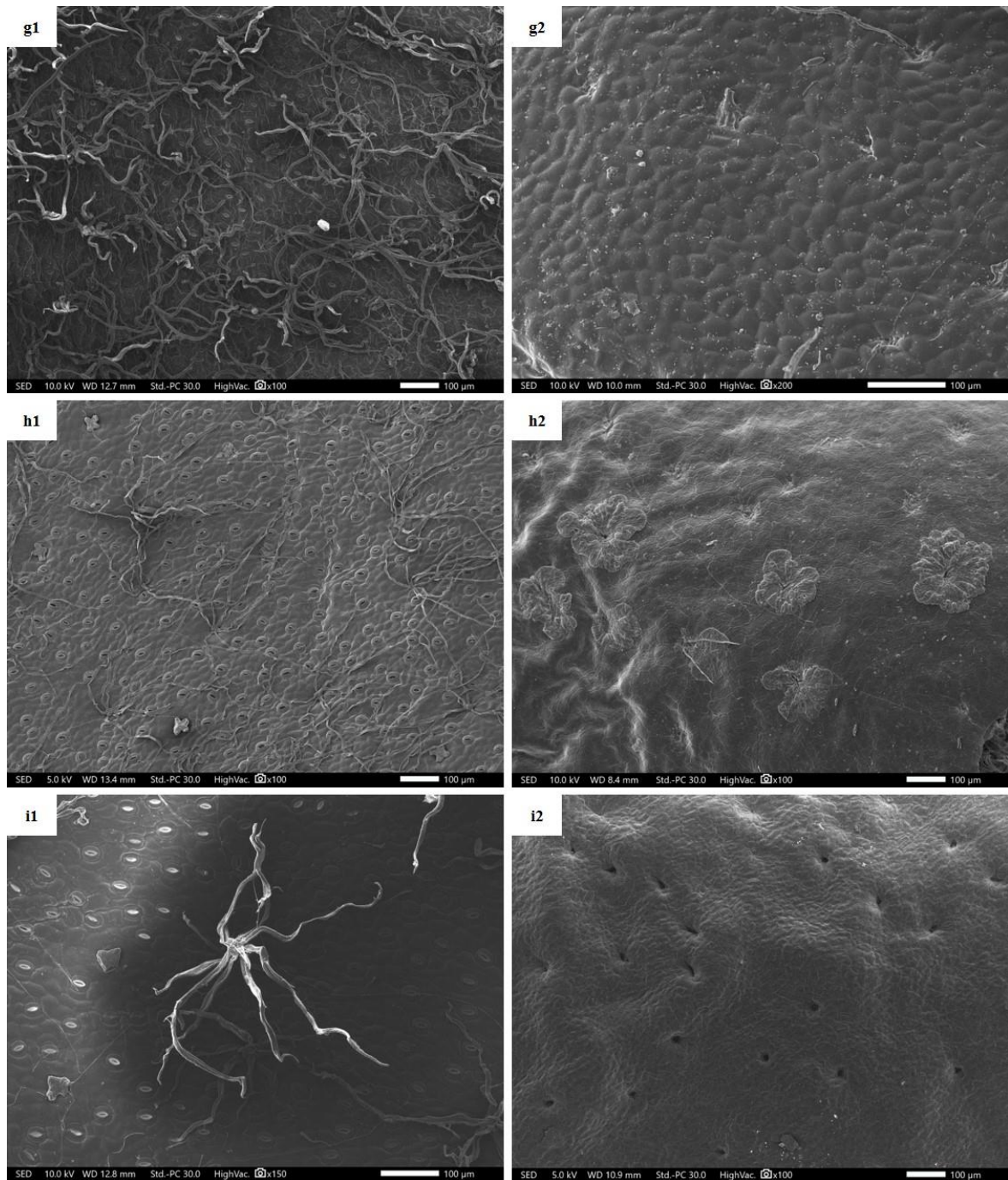


Figure 4.25 continued. (g) *N. mirabilis* var. *echinostoma* (h) *N. nazreeana* sp. nov. ined. (i) *N. rafflesiana*. g1-i1 (Abaxial), g2-i2 (Adaxial). Magnification of g1, h, i2 = x100, magnification of g2 = x200, magnification of i1 = x150, scale bar = 100 μ m

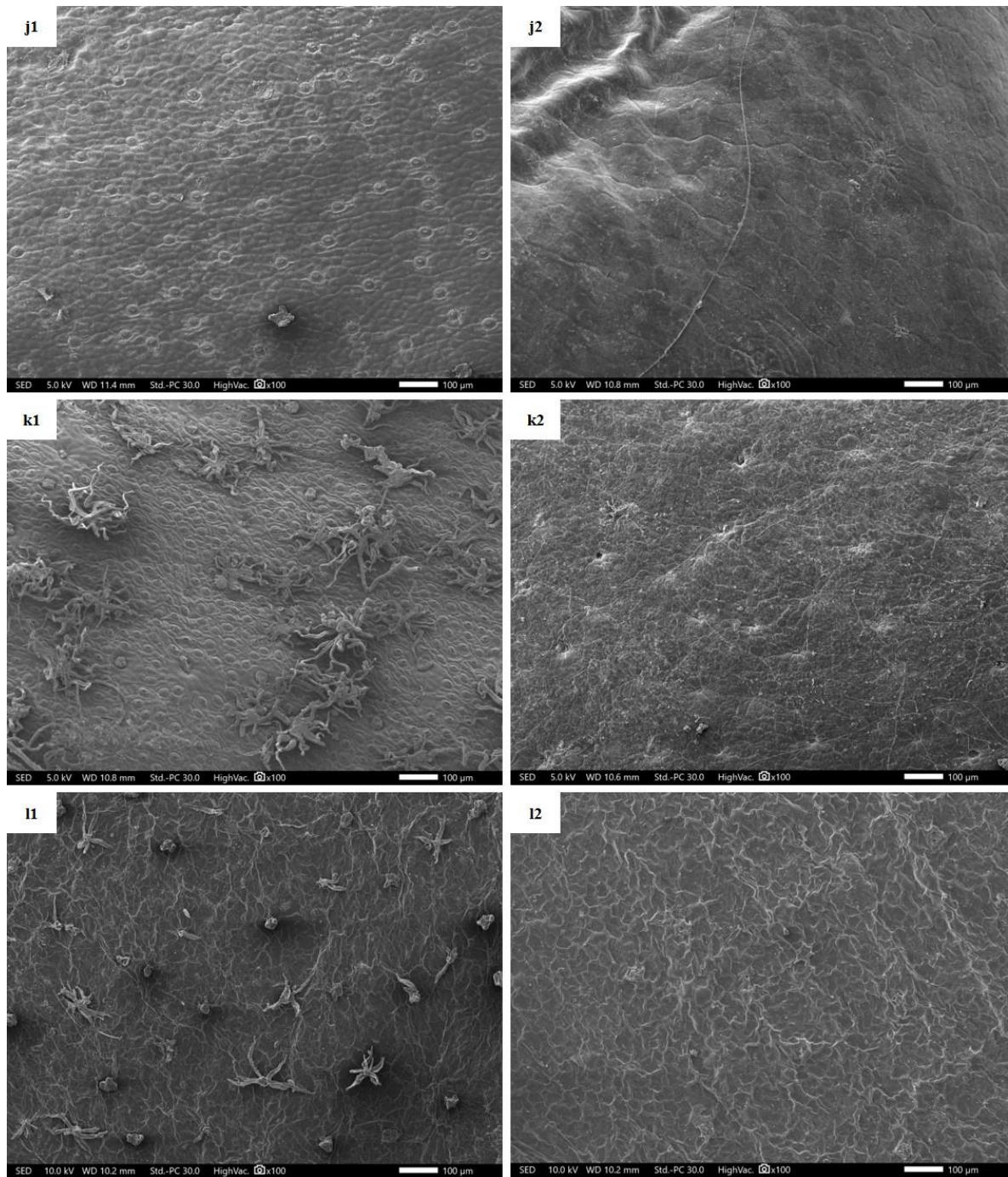


Figure 4.25 continued. (j) *N. reinwardtiana* (k) *N. x hookeriana* (l) *N. x kuchingensis*. j1-l1 (Abaxial), j2-l3 (Adaxial). Magnification of j-l = x100, scale bar = 100 µm

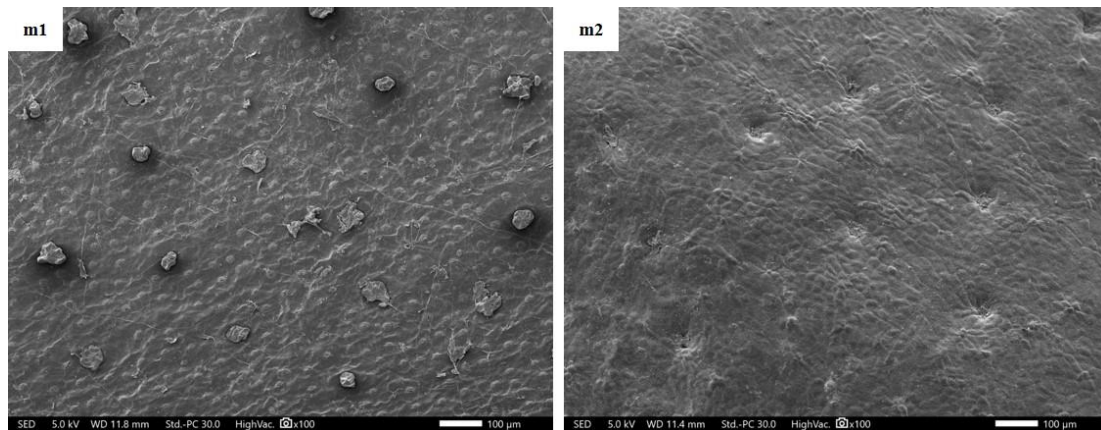


Figure 4.25 continued. (m) *N. x trichocarpa*. m1 (Abaxial), m2 (Adaxial). Magnification of m =x100, scale bar = 100 µm

4.5.3 Lunate Cells and Digestive Glands

The pitchers of 13 different *Nepenthes* species were divided into three zones: Zone 1 (the peristome), Zone 2 (the waxy zone), and Zone 3 (the digestive zone). This research focused on the micromorphological characteristics of the pitcher's inner surface in two zones: Zone 2 and Zone 3. The Zone 2 is located beneath the peristome and is characterised by the presence of lunate cells and wax crystals. The Zone 3 is located at the pitcher's base where the digestive fluids are produced and secreted by the digestive glands. Figure 4.26 depicts both general features of the lunate cell and digestive gland.

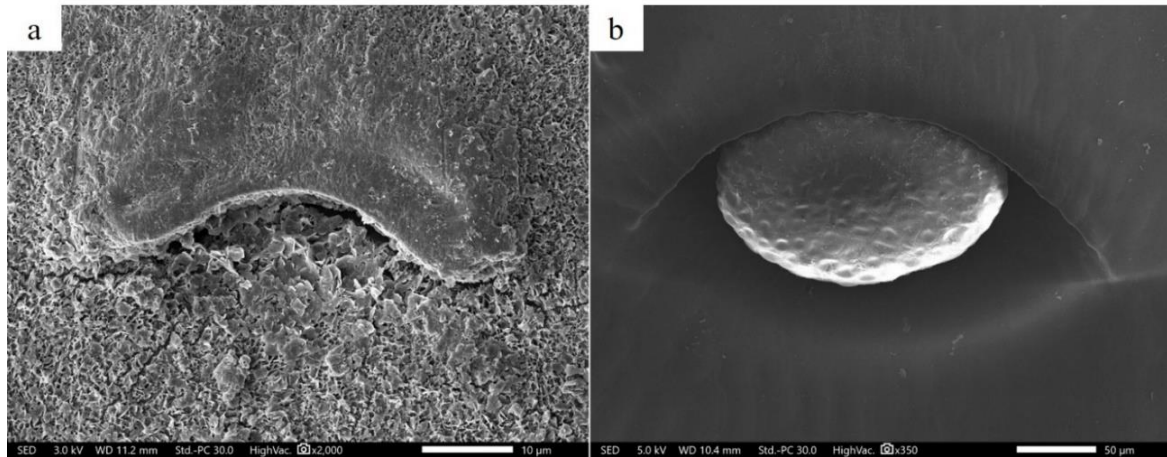


Figure 4.26: Inner surface of the pitcher in *Nepenthes* studied. (a) Lunate cell in the upper part of the pitcher below the peristome is covered with crystal wax. (b) Mature digestive glands half-sink towards the ‘hood’. Magnification a = x2000, scale bar = 10 µm, b = x350, scale bar = 50 µm

4.5.3.1 Lunate Cells

Lunate cells are modified stomatal complexes that are formed below the peristome. They are forming a crescent-like shape, which enlarged guard cells that are bending downwards and elongating horizontally. The micromorphological characteristics of lunate cells in the pitcher were observed and compared between the 13 collected *Nepenthes* taxa. The average lengths and density of lunate cells present in the inner surface of the upper half pitcher showed in Table 4.10.

Table 4.10: The micromorphological characteristics of lunate cells in *Nepenthes* taxa

<i>Nepenthes</i> Taxa	Lunate Cells (Absence/Presence)	Average Length of Lunate Cells (µm)	Density (mm ⁻²)
<i>N. albomarginata</i>	Presence	45.42	81.49
<i>N. ampullaria</i>	Absence	N/A	N/A
<i>N. gracilis</i>	Presence	47.74	244.46
<i>N. hirsuta</i>	Presence	34.95	264.83
<i>N. hispida</i>	Absence	*N/A	*N/A
<i>N. mirabilis</i>	Presence	40.22	271.62

Table 4.10 continued

<i>N. mirabilis</i> var. <i>echinostoma</i>	Presence	48.02	176.56
<i>N. nazreeana</i> sp. nov. ined.	Presence	36.63	122.23
<i>N. rafflesiana</i>	Presence	38.50	156.18
<i>N. reinwardtiana</i>	Presence	40.99	47.53
<i>N. x hookeriana</i>	Absence	*N/A	*N/A
<i>N. x kuchingensis</i>	Absence	30.66	183.35
<i>N. x trichocarpa</i>	Presence	47.15	20.37

*N/A = The measurement value is not applicable for the absence of lunate cells.

The findings revealed that the lunate cells are distributed in different densities below the peristome at the upper half area of the pitcher in ten *Nepenthes* taxa, including *N. albomarginata*, *N. gracilis*, *N. hirsuta*, *N. mirabilis*, *N. mirabilis* var. *echinostoma*, *N. nazreeana* sp. nov. ined., *N. rafflesiana*, *N. reinwardtiana*, *N. x kuchingensis*, and *N. x trichocarpa*. In contrast, the remaining three taxa, *N. ampullaria*, *N. hispida*, and *N. x hookeriana*, were lacking this feature and developed digestive glands directly beneath the peristome.

The density of the lunate cells presence among the *Nepenthes* taxa is different, with *N. mirabilis* having the highest density, 271.62 μm , and *N. x trichocarpa* has the lowest density of lunate cells, 20.37 μm . The lunate cells of each taxon also show a different average length. The shortest length was observed in *N. x kuchingensis* (30.66 μm), while the longest lunate cells can be found in *N. mirabilis* var. *echinostoma*. The lunate cells of the ten taxa were included in Figure 4.27.

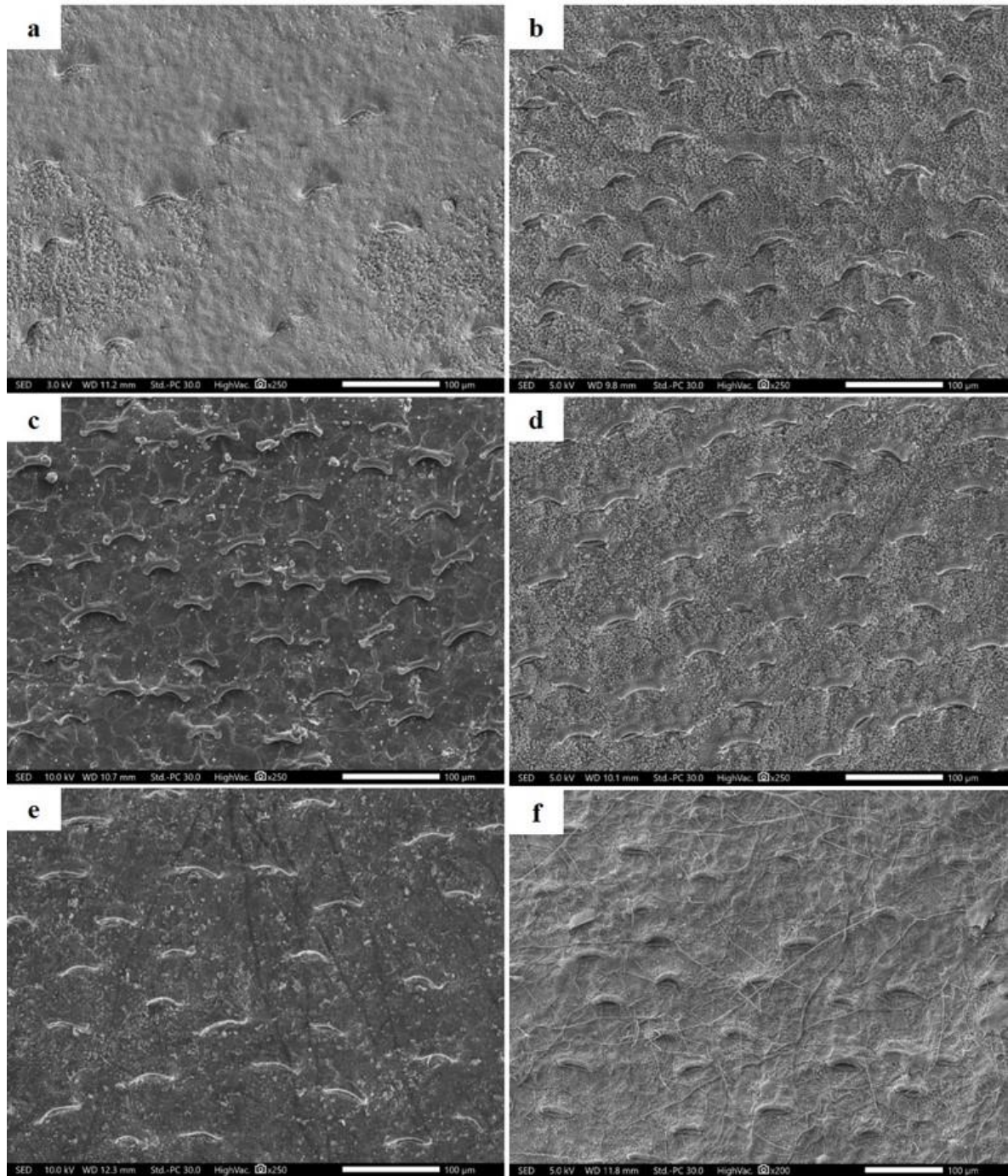


Figure 4.27: Lunate cells in the pitcher of *Nepenthes* studied. (a) *N. albomarginata* (b) *N. gracilis* (c) *N. hirsuta* (d) *N. mirabilis* (e) *N. mirabilis* var. *echinostoma* (f) *N. nazreeana* sp. nov. ined. Magnification a-e = x250, f = x200

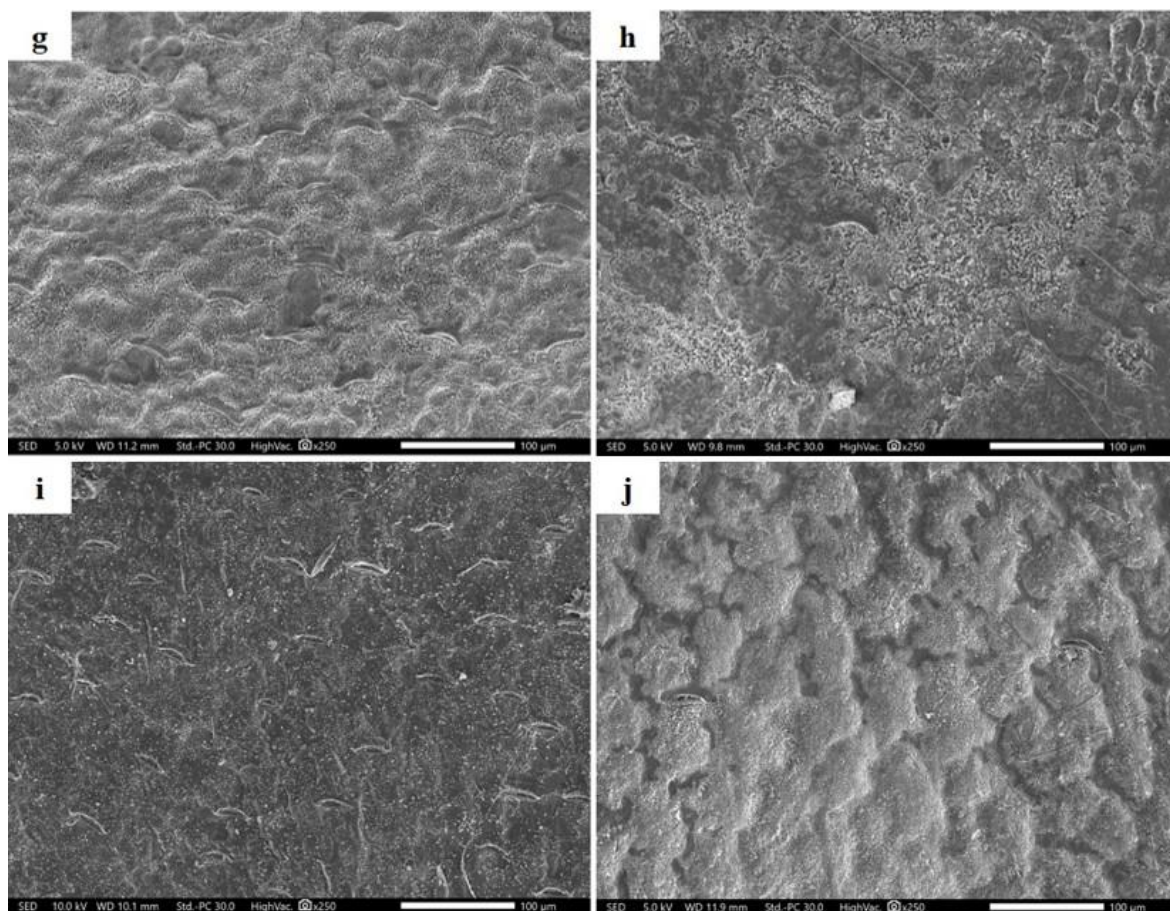


Figure 4.27 continued. (g) *N. rafflesiana* (h) *N. reinwardtiana* (i) *N. x kuchingensis* (j) *N. x trichocarpa*. Magnification g-j = x250

4.5.3.2 Digestive glands

All 13 *Nepenthes* studied consists of an abundance of multicellular digestive glands that are formed from the epidermal cell division in the inner surface of the pitcher at the base (Zone 3). These glands excrete fluids that contain various digestive enzymes such as aspartic proteases and nepenthesins (Nep.) to help in the digestion and absorption of nutrients from the trapped prey (Shulze et al., 1999). Based on observation, the digestive glands are developed in different sizes and densities that slightly sink toward the ‘hoods’. These ‘hoods’ also were assumed to be lunate cells as explained by Owen and Lennon (1999). Obvious differences were noticed in the sizes and densities of digestive glands among the *Nepenthes* taxa studied (Table 4.11).

Table 4.11: Density and average sizes of digestive glands at the inner surface of the lower part of the pitcher in *Nepenthes* studied

<i>Nepenthes</i> Taxa	Average size of digestive glands (μm diam.)	Density of digestive glands (mm^{-2})
<i>N. albomarginata</i>	158.64	11.89
<i>N. ampullaria</i>	82.58	25.47
<i>N. gracilis</i>	237.69	5.09
<i>N. hirsuta</i>	136.12	14.01
<i>N. hispida</i>	129.69	13.25
<i>N. mirabilis</i>	104.24	23.77
<i>N. mirabilis</i> var. <i>echinostoma</i>	N/A	24.20
<i>N. nazreeana</i> sp. nov. ined	113.75	17.83
<i>N. rafflesiana</i>	137.25	44.57
<i>N. reinwardtiana</i>	388.77	5.09
<i>N. x hookeriana</i>	71.81	27.17
<i>N. x kuchingensis</i>	83.33	26.74
<i>N. x trichocarpa</i>	102.76	13.58

N/A = Not available. The digestive glands cannot be fully observed for measurement.

The results revealed that the sizes of digestive glands are varied in diameter among the *Nepenthes* taxa. The lowest average sizes of digestive glands were found in *Nepenthes x hookeriana* with 71.81 μm diam, followed by *N. ampullaria* and *N. x kuchingensis* with 82.58 μm and 83.33 μm diam. respectively. The biggest average sizes of digestive glands were shown in several taxa including *Nepenthes reinwardtiana* (388.77 μm diam.), *N. gracilis* (237.69 μm diam.), *N. albomarginata* (158.64 μm diam.), *N. rafflesiana* (137.25 μm diam.), *N. hirsuta* (136.12), *N. hispida* (129.69 μm diam.), *N. nazreeana* sp. nov. ined. (113.75 μm diam.), *N. mirabilis* (104.24 μm diam.) and lastly, *N. x trichocarpa* (102.76 μm).

Nepenthes reinwardtiana with the biggest sizes of digestive glands exhibit the lowest density of 5.09 mm⁻² among the taxa. Whereas, the highest density of digestive glands was seen in *Nepenthes rafflesiana* with 44.57 mm⁻². The sizes of the digestive glands sometimes influenced the density of digestive glands developed in the inner pitcher of the lower part of each taxon. The observations also show that typically, the bigger the sizes in diameter, the lower the density of the digestive glands distributed in the lower part of the inner pitcher. Nishida and Takahashi (2001) discovered that both of these characteristics were correlated with the acidity level of the digestive fluids. Digestive glands with bigger sizes have higher acidity compared with digestive glands that are low in density and smaller in size.

Schwallier et al. (2020) discovered that there are a few phases of digestive glands development in *Nepenthes*; curvation phase, elongation phase, inflation phase, and maturation phase. The majority of the digestive glands in the *Nepenthes* studied were observed in the inflation phase, and maturation phase (Figure 4.28). The digestive glands are well developed, have more defined circular to elliptical shapes, and sunken towards into their 'hoods'. The observation of digestive glands in *N. reinwardtiana* (Figure 4.28 (j)) shows conspicuous differences from others as the digestive glands are visible faintly and not inflated yet as they are in the early phase of the glands' development.

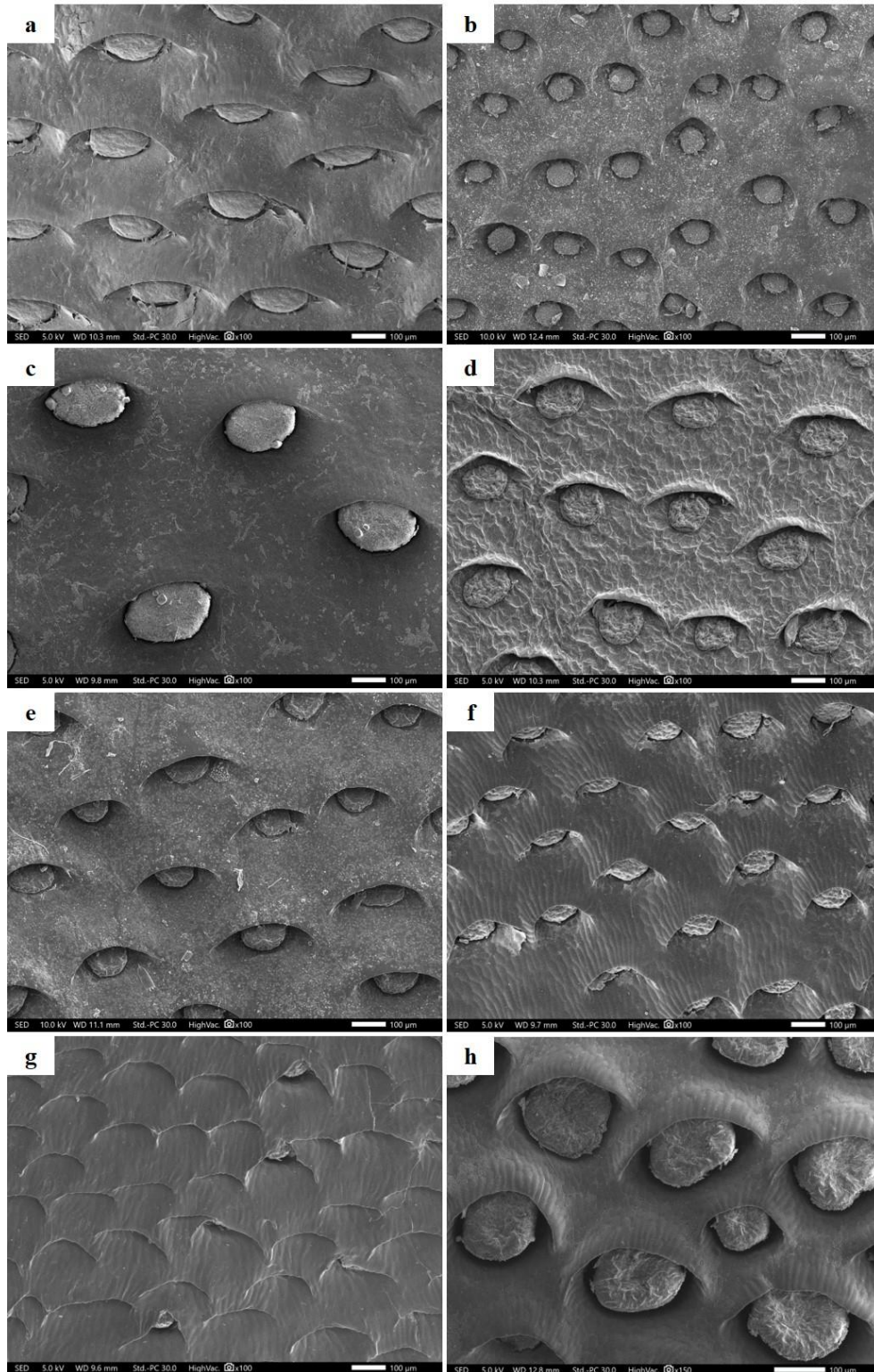


Figure 4.28: Digestive glands of *Nepenthes* studied. (a) *N. albomarginata* (b) *N. ampullaria* (c) *N. gracilis* (d) *N. hirsuta* (e) *N. hispida* (f) *N. mirabilis* (g) *N. mirabilis* var. *echinostoma* (h) *N. nazreeana* sp. nov. ined. Magnification a-g = x100, h = x150

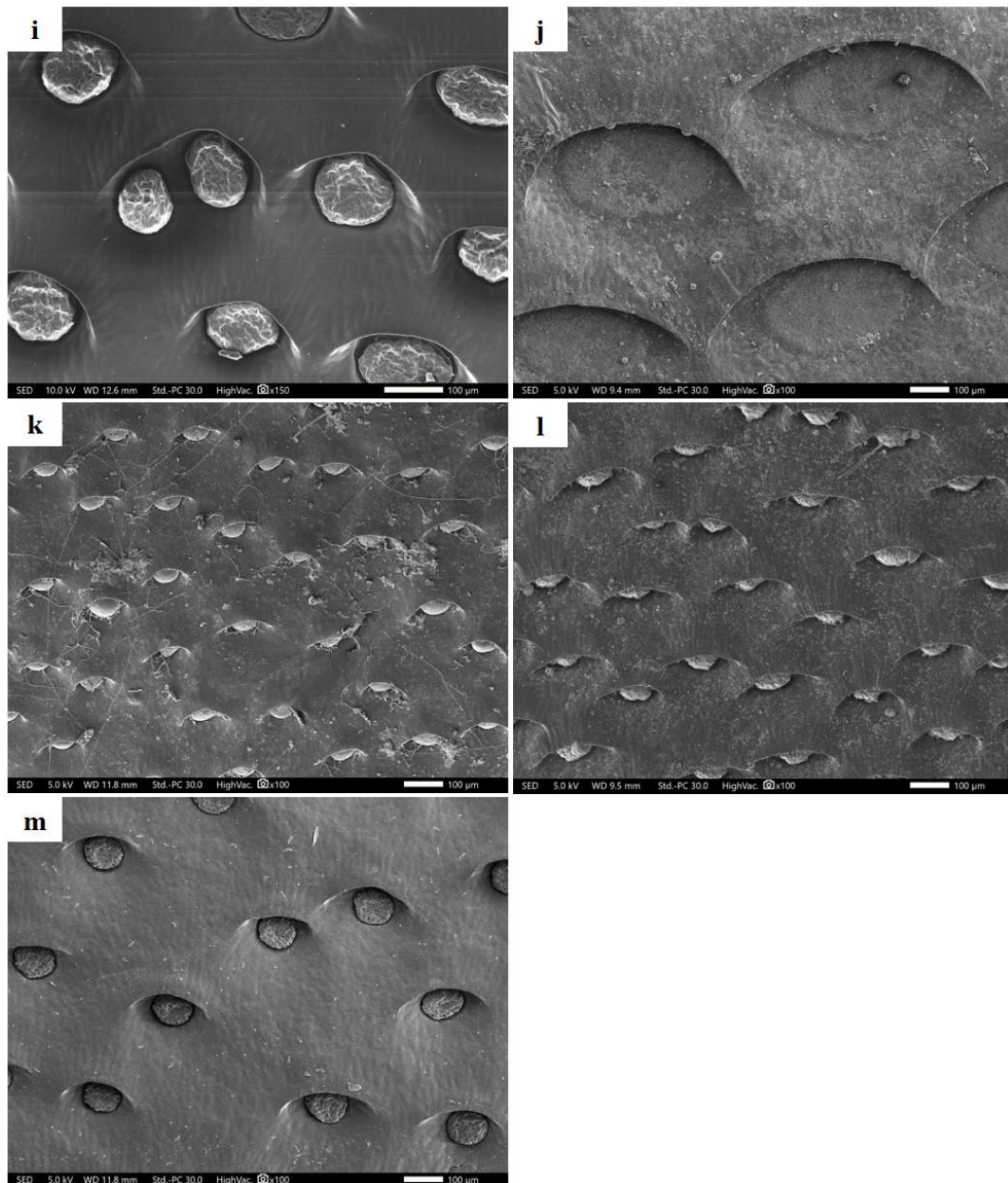


Figure 4.28 continued. (i) *N. rafflesiana* (j) *N. reinwardtiana* (k) *N. x hookeriana* (l) *N. x kuchingensis* (m) *N. x trichocarpa*. Magnification i = x150, k-m = x100

4.6 Palynology

Pollen grains from six *Nepenthes* species in western Sarawak were examined using Field Emission Scanning Electron Microscopy (FESEM); *N. ampullaria*, *N. gracilis*, *N. mirabilis*, *N. nazreeana* sp. nov. ined., *N. rafflesiana*, and *N. reinwardtiana*. The pollen grains were observed produced from the anther of the male inflorescences (Figure 4.29). Five parameters of the pollen grains were; pollen unit, pollen aperture, pollen size, pollen shape, and pollen sculpturing.

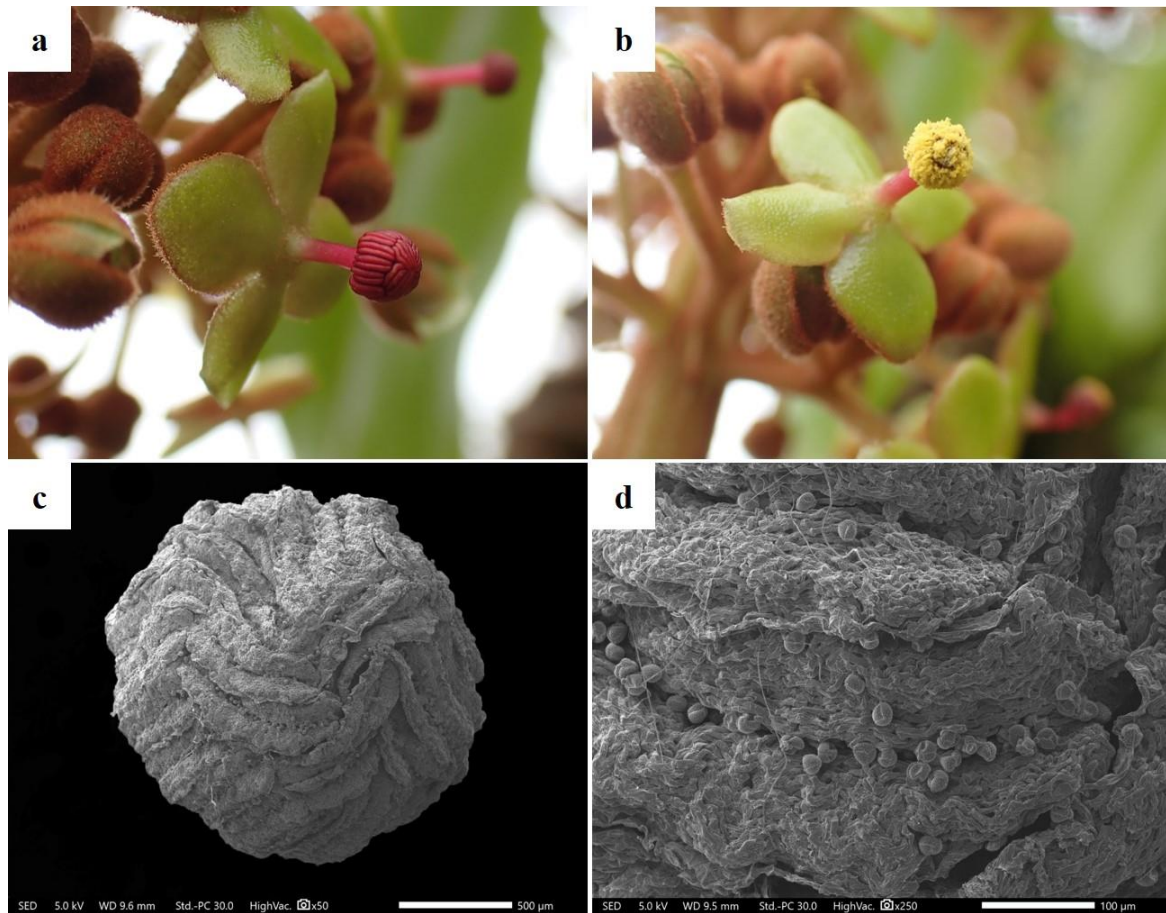


Figure 4.29: Male flowers of *Nepenthes*. (a) anther without the pollen grains (b) matured pollen grains abundantly produced within the anther of the flower (c) observation of the anther part under the Field Scanning Electron Microscopy (FESEM) (d) close up view of pollen grains produced by the anther. Magnification c = x50, scale bar = 500 µm, d = x250, scale bar = 100 µm

4.6.1 Pollen Unit and Aperture

The pollen unit also known as pollen dispersal unit (PDU) by Pacini (1997) to specify the diverse ways of pollen dispersal; monad, dyad, tetrad, pseumomad, massula, pollinium, and pollinarium (Hesse et al., 2009). Meanwhile, the aperture of the pollen is referring to the region where the exine is thinner and forming a gap between the wall. This feature plays an important role as a germination site. The observation of pollen unit and aperture were exhibited in Figure 4.30.

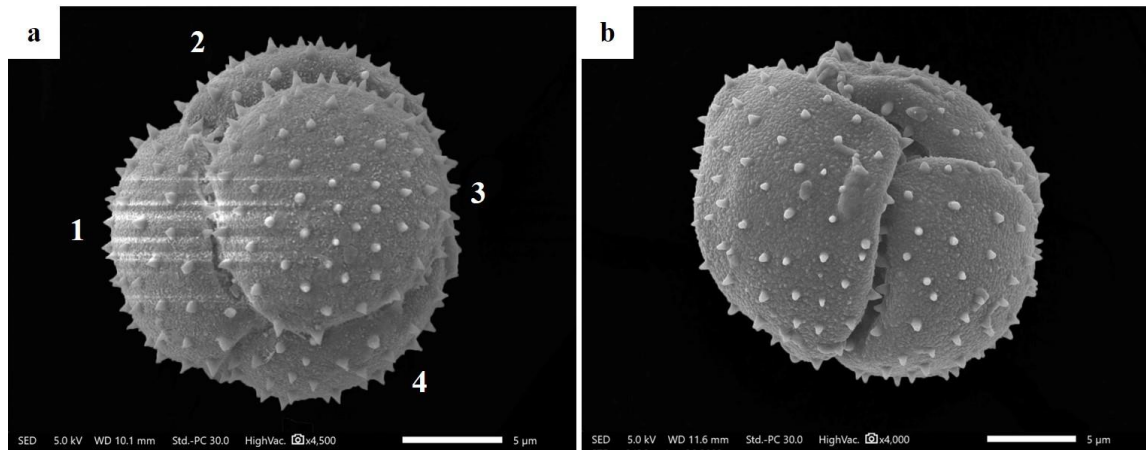


Figure 4.30: Pollen grains of *Nepenthes* studied. (a) equitorial view of pollen grains that shows tetrahedral tetrad unit of pollen (b) polar view of pollen. Magnification a = x4500, scale bar = 5 µm, b = x4000, scale bar = 5 µm

The FESEM observation displayed that the pollen unit of the six *Nepenthes* studied are developed in tetrathedral tetrad. The pollen grains are composed of four single pollen unit which fused and dispersed together. They also were observed lacking in aperture or also called as inaperturate.

4.6.2 Pollen Size and Shape

The pollen shapes; oblate, spheroidal, and prolate are identified based on the P:E ratio, the length of the polar axis (P) to the equatorial diameter (E) of the single pollen unit as explained by Erdtman (1943), and Hesse et al. (2009). Based on the observation, the pollen shape of six *Nepenthes* studied are hard to be determined as the pollen grains are fused together in tetrahedral tetrad unit. However, the pollen tetrad was noticed forming in circular to elliptical shape overall. Also, the pollen tetrad of each *Nepenthes* included were measured in diameter to delimit the six taxa (Table 4.12).

Table 4.12: Pollen tetrad size of six *Nepenthes* studied in western Sarawak

<i>Nepenthes</i> taxa	Mean of pollen size (μm diam.)	Pollen size category
<i>N. ampullaria</i>	19.60	Small
<i>N. gracilis</i>	17.02	Small
<i>N. mirabilis</i>	18.89	Small
<i>N. nazreeana</i> sp. nov. ined.	18.40	Small
<i>N. rafflesiana</i>	18.90	Small
<i>N. reinwardtiana</i>	19.91	Small

The pollen tetrad size of the *Nepenthes* studied were found out ranging from 17.0 to 19.91 μm in diameter. These sizes are identified as small sizes following the size categories by Hesse et al. (2009); very small (<10 μm), small (10-25 μm), medium (26-50 μm), large (51-100 μm), and very large (>100 μm). The smallest size of pollen tetrad was seen in *Nepenthes gracilis* with average 17.02 μm in diameter, while the biggest size of pollen tetrad was observed in *N. reinwardtiana* with average 19.91 μm .

4.6.3 Pollen Sculpturing

Pollen sculpturing is the ornamentation of the pollen wall (sporoderm) mainly the exine surface. The exine is the outermost layer of the pollen grains composed of sporopollenin which acts as an acetolysis and decay resistant biopolymers. The exine surface also are divided into two layers which known as sexine (the outer and structured exine), and nexine (the inner and unstructured exine). Figures 4.31 shows the close up view of the pollen sculpturing of the pollen grains in six *Nepenthes* studied.

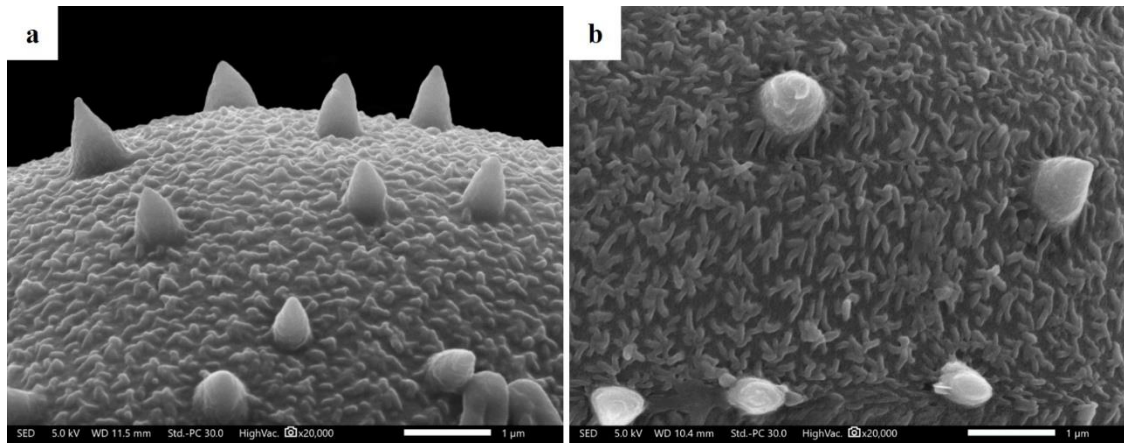


Figure 4.31: Pollen sculpturing. (a) (b) sporoderm of the pollen. Magnification a-b = x20000, scale bar = 1 µm

The examination of the pollen grain under the FESEM revealed that the six *Nepenthes* produced pollen grains with sparsely echinate or echinus ornamentation with microechinate surface on their tectate exine. The echinate structure is long with average length of 1 µm and has sharp pointed apex like a spine. Adam and Wilcock (1998) assumed that these spines feature on the pollen tetrad may help them to adhere to the hairy body of pollinators.

The microechinate structure on the exine also were seen abundantly formed on the surface of the pollen and has average length which significantly smaller than 1 μm . These type of ornamentation, echinate-microechinate were observed form consistently in all pollen tetrad of six *Nepenthes* studied. The representative of pollen tetrad of six *Nepenthes* studies captured in same magnification under the FESEM, x4000 were illustrated in Figure 4.32.

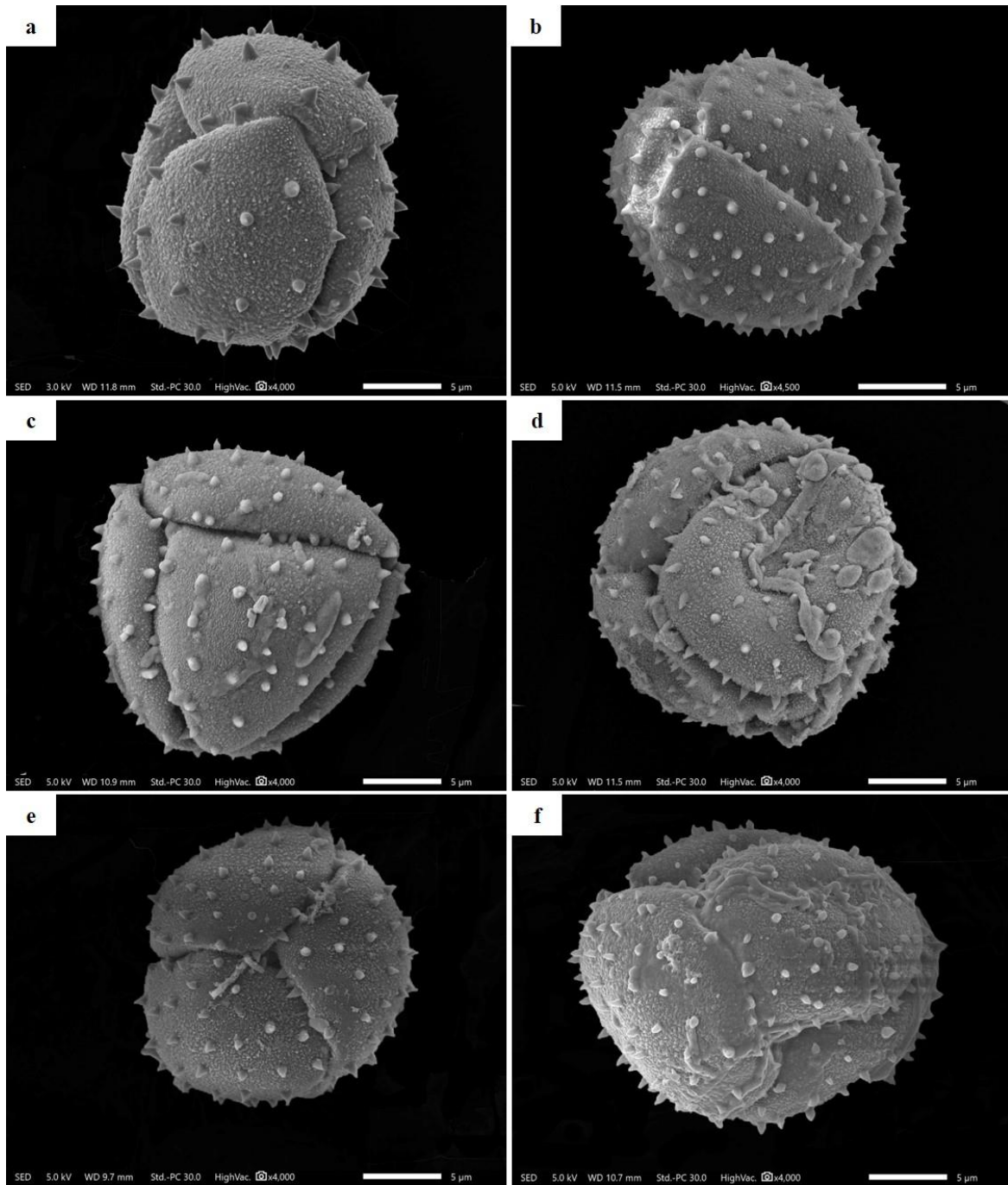


Figure 4.32: Pollen tetrad of six *Nepenthes* studied. (a) *N. ampullaria* (b) *N. gracilis* (c) *N. mirabilis* (d) *N. nazreeana* sp. nov. ined. (e) *N. rafflesiana* (f) *N. reinwardtiana*. Magnification a-f = x4000, scale bar = 5 µm

4.7 Species Treatment

4.7.1 General Description of Genus *Nepenthes* L.

Nepenthes L., Sp. Pl. (1753) 955; Jebb & Cheek, Blumea 42 (1997) 5. — Type species: *Nepenthes distillatoria* L. *Bandura* Adans., Fam. 2 (1763) 75. — Type species: *Nepenthes distillatoria* L. *Phyllamphora* Lour., Fl. Cochin. 2 (1790) 606. — Type species: *Nepenthes mirabilis* (Lour.) Druce. *Anurosperma* (Hook.f.) Hallier f., Bot. Centralbl. 39, Abt. 2, 1 (1921) 162. — Type species: *Nepenthes pervillei* Blume.

Carnivorous, dioecious, woody or subwoody climbers or subshrubs, terrestrial or epiphytic.

Stems terete or 2 – 4-angled, or winged. Buds naked, lacking scales. **Phyllotaxy** spiral, 2/5 or 1/2. **Leaves** exstipulate; involute or convolute, marcescent, simple, chartaceous or coriaceous, petiolate or sessile; midrib extended into an unbranched tendril, the distal part of which expands into an elaborate, animal trapping receptacle (pitcher) containing digestive fluid. **Pitchers** dimorphic. **Lower pitchers** produced from rosettes or short stems, often resting on the ground, usually ovoid or globular, the mouth facing towards the stem, with two ventral fringed wings running from the base to the pitcher rim and with the tendril straight, not coiled. **Upper pitchers** (usually absent in *N. argentii*, *N. ampullaria*, and *N. pectinata*) usually more elongated and infundibuliform (funnel-shaped) than the lower pitchers, the mouth facing away from the stem, the wings reduced to ridges and not fimbriate, or absent, and the tendril coiled. Pitcher mouth apical or subapical, rimmed with a ribbed peristome (except *N. inermis*), the inner edge often toothed and bearing nectar glands, at the rear sometimes raised to form a column, supporting the lid; lid usually held over the mouth (reflexed e.g. in *N. dubia*), lower surface with a laterally flattened basal appendage, rarely an apical filiform appendage, or appendages absent; nectar glands usually abundant; spur inserted on dorsal surface at junction with lid, entire or variously divided, flattened or terete. **Inflorescence** terminal, appearing lateral by subsequent growth, a paniculoid thyrse or

raceme, of 6-300 flowers, the main axis with indeterminate growth, the partial inflorescences 1-flowered (racemose) or 2-flowered, less usually 3–40-flowered, bracteate or ebracteate. Perianth imbricate, a single whorl of 4 (also interpreted as two whorls of 2) free or basally united, patent, nectariferous tepals. Female flowers with androecium lacking, ovary superior, 4-carpellate, incompletely 4-locular locules antitepalous, placentation lamellar, ovules erect, anatropous, bitegmic, crassinucellate, 200-500, stigmas sessile, as many as locules. Male inflorescence usually larger and more floriferous, perianth as in female; stamens 4–12, filaments united into an androphore, anthers tetrasporangiate, in 1-3 dense whorls, united into a subspherical anther head, locules opening by longitudinal slits, extrorse; gynoecium lacking. **Fruit** sometimes stipitate, a loculicidally dehiscent capsule with 4 valves containing 50-500 seeds. Seeds filiform, 3-25 mm long, slender due to long basal and apical appendages. Testa reduced to an outer epidermis with thick outer walls to the cells and irregular thickenings on the radial and inner walls. Tegmen produced only around the embryonic cavity, crushed. Endosperm starchy or absent. Embryo minute, central, straight or U-shaped in a subellipsoid cavity, cotyledons and hypocotyl well-developed, though minute. **Indumentum** of simple, bifid, fasciculate, stellate, dendritic non-glandular and sunken, sessile or shortly stipitate glandular hairs. **Colour** of pitchers entirely green, or yellow or orange or white or purple or red, often marked with red streaks or blotches; peristome often glossy red; inflorescence with green, brown or red tepals. $2n = 80$

4.7.2 Key to *Nepenthes* L. taxa studied in western Sarawak

1a. Lower leaves with fimbriate margin.....	<i>N. mirabilis</i>
1b. Lower leaves with entire margin.....	2
2a. White-collared band presence beneath the peristome.....	<i>N. albomarginata</i>
2b. White-collared band absence beneath the peristome.....	3
3a. Pitcher with two-eye spots at the inner surface.....	<i>N. reinwardtiana</i>
3b. Pitcher without two-eye spots at the inner surface.....	4
4a. Lid with tentacles on the adaxial near the margin.....	<i>N. tentaculata</i>
4b. Lid without tentacles on the adaxial near the margin.....	5
5a. Peristome apex with 2 huge thorns; lid reniform.....	<i>N. bicalcarata</i>
5b. Peristome apex without 2 huge thorns: lid not reniform.....	6
6a. Peristome ribs attached at the outer edge only.....	<i>N. mirabilis</i> var. <i>echinostoma</i>
6b. Peristome ribs attached at the inner and outer edge.....	7
7a. Stems cylindrical.....	8
7b. Stems angular.....	9
8a. Peristome elongated into flattened neck.....	<i>N. rafflesiana</i>
8b. Peristome not elongated into flattened neck.....	10
9a. Leaf deccurent or forming saddles on stem.....	<i>N. northiana</i>
9b. Leaf deccurent without forming saddles on stem.....	11
10a. Lid notched at the apex.....	<i>N. x hookeriana</i>
10b. Lid without notched at the apex.....	12
11a. Pitcher slenderer in shape.....	<i>N. gracilis</i>
11b. Pitcher less slender in shape.....	<i>N. x trichocarpa</i>
12a. Leaves petiolate.....	13
12b. Leaves sessile to weakly petiolate.....	14
13a. Leaf base sheathing.....	<i>N. veitchii</i>
13b. Leaf base not sheathing.....	15
14a. Leaf amplexicaul at the base.....	<i>N. hispida</i>
14a. Lid not amplexicaul at the base.....	16
15a. Stem densely covered with long brown hairs, 1–2 mm long.....	<i>N. hirsuta</i>
15b. Stem less covered with hairs.....	<i>N. nazreaana</i> sp. nov. ined.
16a. Lid as large or larger larger than the pitcher mouth.....	<i>N. x bauensis</i>

- 16b. Lid narrow, smaller than the pitcher mouth.....17
- 17a. Pitcher urceolate, ... *N. ampullaria*
- 17b. Pitcher globose at the base, narrowing to cylindrical at the base..... *N. x kuchingensis*

4.7.3 Descriptions of 18 *Nepenthes* L. taxa studied

1. *Nepenthes albomarginata* T. lobb ex Lindl.

Gard. Chron. (1849) 580; Macfarl. in Engl., Pflanzenr. 4,3 (1908) 37; Danser, *Bull. Jard. Bot. Buitenzorg* III, 9 (1928) 262; Shivas, *Pitcher Plants of Peninsula Malaysia & Singapore* (1984) 25; Tamin & M. Hotta in M. Hotta, *Diversity and Dynamics of Plant Life in Sumatra* (1986) 80; Philipps & A.L. Lamb, *Pitcher Plants of Borneo* (1996) 65, f. 38; Jebb & Cheek, *Blumea* 42 (1997) 16; Clarke, *Nepenthes of Borneo* (1997) 62.

Type Specimen: Gard. Chron. 1849, p. 580, t. 3 (lecto).

Synonym: *Nepenthes laevis* C. Morren; *N. tomentella* Miq.; *N. albomarginata* var. *villosa* Hook. f.; *N. albomarginata* var. *typica* Beck.; *N. albomarginata* var. *rubra* Macfarl. *N. albocincta* var. *rubra* Hort. ex Macfarl.

Description: Terrestrial rosette to 5 cm or climber to 2 m tall. **Stem** woody, terete, slightly flexuose, 3.4–3.45 mm diam. **Leaves** rosette, sessile, coriaceous, 1.3–1.6 x 10.2–14.2 cm, slightly perfoliate, blade oblanceolate – spatulate, apex acute, base slightly attenuate, non-petiolate, leaves decurrent into stem, c. 4 mm long; margin entire, slightly folding inward. Tendril c. 2.5 cm, uncoiled, 2.6 mm. **Lower pitcher** ellipsoid at the base, tapering gradually into cylindrical at the upper half, 4.5–9.5 × 1–2 cm at base, tapering to 0.8–1.5 cm with two wings, fringe elements c. 4 mm long; peristome mouth ±ovate–oblique, 9.45–14.9 mm × 8.55–16.65 mm, ribs closely spaced and very fine, inner edge of peristome lacking of teeth,

presence of white ring (sometimes pale brown) below the peristome, densely packed with trichome, 35 mm wide; neck c. 5 mm; spur 2-branched, 5 mm long; lid ovate, 2.3×2.0 cm, midline pronounced at the abaxial, slightly pronounced keel, covered with hairs at the adaxial and abaxial, nectar glands scattered on the abaxial, elliptic, crater-like. **Upper pitchers** as lower pitchers but cylindrical to infundibulate, $8.5\text{--}13 \times 2\text{--}3$ cm; with two ridges to 1 mm broad, lacking fringed wings. **Indumentum** distributed all over the leaves, body of pitcher, lid, tendrils, brown. **Colour** of leaves light green with few red freckles, midrib brown, pitcher light green, slightly whitish, inner pitcher light green spotted with red-purplish, peristome light green with few red blade lines.

Specimen Examined: Sarawak, Kuching Division, Bako NP, kerangas forest, Sept 2020, *Nabilah Huda et al.*, NH0017; NH0018 (Herbarium Universiti Malaysia Sarawak); Kubah NP, summit trail, kerangas forest, 13 Nov 2021, *Nabilah Huda et al.*, NH0022 (Herbarium Universiti Malaysia Sarawak); Gunung Pueh NP, Kerangas forest, 16 Mar 2021, *Meekiong, K et al.*, NH0038 (Herbarium Universiti Malaysia Sarawak).

Etymology: The epithet name was derived from latin words which are *albus* (white) and *marginatus* (margin) referred to its distinguished characteristics, white band under the peristome.

Habitat and Ecology: Lowland area from sea level to 1000 m a.s.l at the sandstone plateau area, kerangas forest, submontane forest, and limestone area.

Distribution: Borneo, (Sabah, Sarawak, Kalimantan), Sumatra, and Peninsular Malaysia

Conservation status: Least Concern (LC) and the the population are considered stable according to IUCN (Clarke, 2018b). Most of the populations recorded in the TPA areas.

2. *Nepenthes ampullaria* Jack.

Nepenthes ampullaria Jack, Comp. Bot. Mag. (1835) 271; Danser, Bull. Jard. Bot. Buitenzorg III, 9 (1928) 265; Sh. Kurata, Gard. Bull. Sing. 26 (1973) 227; *Nepenthes* of Mt Kinabalu, Sabah (1976) 34; Shivas, Pitcher Plants of Peninsula Malaysia & Singapore (1984) 27; Tamin & M. Hotta in M. Hotta. Diversity and Dynamics of Plant Life in Sumatra (1986) 81; Jebb, Science in New Guinea 17 (1991) 21, f. 4 & 8; Phillipps & A.L. Lamb, Pitcher Plants of Borneo (1996) 67, f. 40; Jebb & Cheek, Blumea 42 (1997) 18; Clarke, *Nepenthes* of Borneo (1997) 65, f. 40-43.

Type specimen: Jack s.n. (lecto SING), Singapore.

Synonym: *Nepenthes ampullaceae* H. Low, *N. ampullaria* var. *guttata* Moore, *N. ampullaria* var. *vittata* major Mast., *N. ampullaria* var. *vittata* Andre, *N. ampullaria* var. *geelvinkiana*, *N. ampullaria* var. *longicarpa*, *N. ampullaria* var. *microsepala* Macfarl., *N. ampullaria* var. *racemosa* J.H. Adam & Wilcock, *N. ampullaria* auct. non Jack.

Descriptions: Terrestrial aerial rosettes or climber at about 2 m. **Climbing stem** cylindrical, 4.5–5.4 cm diam., internodes 0.5–5.7 cm. **Leaves** of climbing stem sessile, sometimes with a short and poorly defined petiole, c. 1–3 cm, blade thickly chartaceous, ±obovate-spathulate, 5–11.6 x 2.2–3.7 cm, apex acute or slightly rounded, rarely acuminate, base cuneate, petiole winged to 5–8 mm wide at each side of the rib, clasping the stems half of its circumference, decurrent by c. 5 mm. Longitudinal nerves 2–3 at each sides of the midrib near to the margin, indistinct, pennate nerves numerous, 45° ascending from the midrib, obscure at the lower surface of the leaves. **Lower pitcher** obliquely urceolate, ventral side flat, dorsal side semi-circular, 2.4–4.5 x 1.4–3 cm; fringed wings presence, c. 2–7 mm wide, fringe elements up to 4 mm, c. 1–2 mm apart, distance between 2 fringed wings up to 1.8

cm; mouth oval, 14.36 x 12.28 mm wide; peristome flattened inwards, 0.5– 1.2 cm wide; lid narrowly oblanceolate, 0.8–2.0 x 0.3–0.7 cm, apex rounded, very slightly acute, base cuneate, presence of 2 pronounced midribs near to the margin. **Upper pitcher** usually not developed but sometimes about 1–2 developed. **Male inflorescence** panicle, rachis about 15 cm long, canaliculate, peduncle 5.5–8.8 cm long, c. 4.42 mm diam, pedicel c. 1.0 cm, flowers mature from bottom to upper, 2–5 flowers per pedicel, tepal 5–7 x 5–6 mm, broadly elliptic, apex acute, base cuneate; androphore 3–5 mm, anther head c. 1.4 mm, pollen yellow. **Female inflorescence** panicle, bearing about 150 flowers, rachis 19 cm, slightly canaliculate, peduncle 8.8 cm long, 4.30 mm diam, pedicel 1–1.2 cm, tepal 4, ovate, c. 5–7 x 4–5 mm, apex acute, base cuneate. **Indumentum** simple, c. 2–3 mm long, brownish red, densely velvety on the young part, abaxial of leaf, stem, inflorescence, young pitchers. **Colour** of leaves light green at the abaxial and adaxial, midrib bright red-purple on the adaxial, pitcher light green or light green and flecked with maroon-purple, peristome light green and sometimes with red ribs tepal of male inflorescence red-purple, tepal of female inflorescence light greenish yellow.

Specimens Examined: Sarawak, Kuching Division, Mount Santubong NP, loop trail, keranags forest, 8 March 2020, *Nabilah Huda* et al., *NH0008*; *NH0009*; *NH0010* (Herbarium Universiti Malaysia Sarawak); Matang-Sampadi Roadside, disturbed kerangas area, 23 Oct 2020, *Nabilah Huda* et al., *NH0023* (Herbarium Universiti Malaysia Sarawak); Bra'ang Roadside, peatswamp to kerangas forest, 29 Oct 2020, *Nabilah Huda* et al., *NH0026* (Herbarium Universiti Malaysia Sarawak); Bau, Banjaran Undan, Stenggang Dam trail, mixed dipterocarp forest, 19 Dec 2020, *Nabilah Huda* et al., *NH0034* (Herbarium Universiti Malaysia Sarawak); Aquilaria Plantation, near the roadside, peat swamp forest, 3 Dec 2020,

Nabilah Huda et al., NH0027 (Herbarium Universiti Malaysia Sarawak); Bra'ang Roadside, kerangas forest, 29 Oct 2020, *Nabilah Huda et al., NH0026* (Herbarium Universiti Malaysia Sarawak); Samarahan Division; Kota Samarahan; Universiti Malaysia Sarawak, peatswanp forest, Jalan Kapur roadsides, Dec 2019, *Nabilah Huda et al., NH0003* (Herbarium Universiti Malaysia Sarawak)

Etymology: The epithet name of *ampullaria* was adapted from a Latin word, *ampulla* which means flask. This species also was recognised with a vernacular name, Flask-shaped pitcher plant.

Habitat and Ecology: *Nepenthes ampullaria* grows in the damp and shady area or forest as a rosette or terrestrial climber associated with other species which is Glechenia fern and dipterocarp tree. But, sometimes can be found in open or highly sun exposed area mostly at the roadside embankments. This lowland species (sea level to 2100 m.a.s.l) prefers acidic and moist soils on a peat, sandy–clay soil, kerangas, and sandstone area.

Distribution: Borneo, Peninsular Malaysia. Sumatra, Singapore, Thailand, New Guinea.

Conservation status: *Nepenthes ampullaria* has been categorised as Least Concern (LC) species based on the assessment by Clarke (2018c) in the IUCN Red List.

Notes: *Nepenthes ampullaria* is one of the species that is commonly used to make *Lemang Periuk Kera*, a traditional rice dishes in Malaysia. This species is known as detrivores which they collect leaf litters that fall down into their pitchers.

3. *Nepenthes bicalcarata* Hook. f.

Nepenthes bicalcarata Hook.f. in A.DC, Prodr. 17 (1873) 97; Becc, Malesia 2 (1886) 231, t. 55; Danser, Bull. Jard. Bot. Buitenzorg III, 9 (1928) 270; Sh. Kurata, *Nepenthes* of Mt Kinabalu, Sabah (1976) 37, t. 8; Philipps & A.L. Lamb, Pitcher Plants of Borneo (1996) 70, f. 41; Jebb & Cheek, Blumea 42 (1997) 24; Clarke, *Nepenthes* of Borneo (1997) 68, f. 43 & 44. — Type: Low s.n. (lecto K; iso K), Borneo, Sarawak, Lawas River.

Type specimens: Low s.n. (lecto K; iso K), Borneo, Sarawak, Lawas River.

Synonym: *Nepenthes dyak* S. Moore.

Description: Terrestrial climber up to 15 m tall. **Stem** terete, c. 1.8 cm diam., sometimes hollow with small circular entrance holes cut by ants, internodes 0.5–8 cm long. **Leaves** thickly chartaceous, petiolate, oblong-lanceolate, 48.76–56 × 11.47–12.78 cm, apex acute, base attenuate; petiole narrowly winged, 9.5–10 long, clasping the stem for 3/4 of its circumference, petiole wings sometimes decurrent to next node, usually large rimmed nectaries present on lower surface of petiole immediately adjacent to stem. Longitudinal nerves 10 or more on each side of the midrib. Pennate nerves patent, numerous, distinct almost to leaf margin. Tendril of lower pitcher swollen, to 12 mm thick, and with a thin-walled spot which is usually hollowed and inhabited by an ant colony, entrance hole facing towards pitcher surface; tendril of upper pitcher only once coiled, coil in contact with the dorsal surface of pitcher, and it is at this point that the entrance hole to the hollow tendril lies. **Lower pitchers** globose, 6–11.8 × 6–8.7 cm; with 2 fringed wings to 1.2 cm broad, fringed elements to 1.0 cm long, up to 2 mm apart; nectaries scattered on pitcher surface, especially dorsally, on ventral wings and on tendril; mouth suborbicular, straight and almost horizontal at front, rising abruptly at rear and forming a stout vertical or overarching column;

peristome with outer edge cylindrical, c. 4 mm wide, inner edge flat, 1-2 cm wide, ribs 0.2-0.5 mm apart, inner margin with teeth c. 0.6 mm long, with a pit between each tooth; the apical most 10-12 ribs of the column drawn out into a pair of long downward curving acute thorns up to 2 cm long; lid reniform, much wider than long, 3.6–4 × 4.2–5 cm, glands thinly bordered, circular, c. 0.3 mm diam., densest towards the two sides, ± absent towards centre and near junction with pitcher; spur simple, flattened, recurved, glandular, up to 7 mm long. **Indumentum** sparse on leaves and stem, dense on pitchers and inflorescence; on the latter of two kinds, a dense short pubescence, and scattered longer hairs of 1-2 mm. **Colour** not seen as the examination were made on the herbarium specimens.

Etymology: The name *bicalcarata* is a combination of two Latin words, *bi* = two, and *calcaratus* = spurred, which referring to the character of two long fangs developed at the base of the lid towards the mouth of pitcher.

Specimens Examined: Sarawak, Kuching Division, Loba Kara, *J.A.R. Anderson*, 16 Apr 1954, S2820A (SAR) (Figure 4.34); Sri Aman Division, Betong, Saribas FR, peat swamp forest, 13 August 1957, *J.A.R. Anderson*, S8533 (SAR) (Figure 4.33).

Habitat and Ecology: Grow at the altitude from seal level to 950 m a.s.l, commoly at the peat swamp forest which dominated by dipterocarp trees, *Shorea albida*, and at the heath forest.

Distribution: Endemic to Borneo. Particularly in Sarawak, Southwest of Sabah, Brunei, and Northwest of Kalimantan.

Conservation status: *Nepenthes bicalcarata* has been assessed as Vulnerable (VU) in 2000 by Schnell et al. (2000a) in the IUCN Red List. The population of this species are declining.

Notes: This species developed special features, two huge and sharply pointed thorns that are developed from the apex of the peristome, near the base of the lid. The thorns are projecting downward into the mouth of the pitcher. Also, these thorns bearing nectary glands at their apex that were acts as defence mechanism from the predatory animals or attracting and trapping prey mechanism (Burbidge, 1988; Clarke, 1993). *Nepenthes bicalcarata* has ant-hollowed tendrils and stems that are occupied by small red ants, *Camponotus schmitzii* that gain their food resources from the the pitcher fluid (Jeeb and Cheek, 2001).



Figure 4.33: Herbarium specimen of *Nepenthes bicalcarata*. Sarawak, Sri Aman Division, Betong, Saribas FR, peat swamp forest, 13 Aug 1957, Anderson, J. A. R., S8533 (SAR)



Figure 4.34: Herbarium specimen of *Nepenthes bicalcarata*. Sarawak, Kuching Division, Loba Kara, 16 Apr 1954, Anderson, J. A. R., S2820A (SAR)

4. *Nepenthes gracilis* Korth

Nepenthes gracilis Korth., Kruidkunde, in Temminck, Verh. Nat. Gesch. (1840) 22, t. 1 & 4; Danser, Bull. Jard. Bot. Buitenzorg III, 9 (1928) 290; Sh. Kurata, Gard. Bull. Sing. 26 (1973) 229; Shivas, Pitcher Plants of Peninsula Malaysia & Singapore (1984) 29; Tamin & M. Hotta in M. Hotta, Diversity and Dynamics of Plant Life in Sumatra (1986) 86; Philipps & A.L. Lamb, Pitcher Plants of Borneo (1996) 89, f. 49; Jebb & Cheek, Blumea 42 (1997) 42; Clarke, *Nepenthes* of Borneo (1997) 90, f. 59 & 60; J.H. Adam & Wilcock, Sarawak Mus. J. 50 ('1996', 1998) 159.

Type specimens: Korthals s.n. (lecto L; iso K), Borneo, G. Pamatton, 325 m.

Synonym: *Nepenthes laevis* Lindl. (non *N. laevis* C. Morren = *N. albomarginata*), *N. gracilis* var. *elongata* Blume, *N. korthalsiana* Miq., *N. teysmanniana* Miq., *N. gracilis* var. *teysmanniana* (Miq.) Beck, *N. tupmanniana* Bonstedt, *N. laevis* Korth. ex Hook. f., *N. angustifolia* Mast., *N. gracilis* var. *longinodis* Beck, *N. gracilis* var. *arenaria* Ridl. ex Macfarl., *N. distillatoria* auct. non L.: Jack.

Descriptions: Terrestrial climber up to 5 m tall. **Climbing stem** woody, triangular, 2.8–4.8 cm diam, internodes 2–6 cm long. Leaves chartaceous, sometimes coriaceous, 9.4–12.6 cm x 2.2–2.5 cm, blade narrowly lanceolate, apex acute, rarely acuminate, base sessile, slightly narrow, subpeltate, clasping the stem at half of its circumference, decurrent by 3–6 mm, margin entire. Longitudinal nerves 3–4 at each side of the midrib near to the margin. Pennate nerves numerous, indistinct. Tendril 7.5–9 cm long, coiled once at the middle. **Lower pitcher** slender, base ellipsoid and abruptly slightly constricted towards the subcylindrical at the upper half of the pitcher body, 5.7–7.2 x 1.2–1.8 cm, fringed wings absent, 2 ribs developed at the frontal side of pitcher; mouth ± ovate, slightly rounded, 9.63–12.19 x 14.6–

15.12 mm; peristome ribs very fine, teeth lacking. **Upper pitcher** as the lower, but subcylindrical and gradually and slightly constricted in the middle, $5.5\text{--}7.5 \times 1.2\text{--}2$ cm, with two ridges c. 1 mm broad, lacking fringed elements. **Male inflorescence** 13.5–15 cm; peduncle 3–3.5 cm long, 1.5 mm diam. at base; partial peduncles 1-flowered; bracts usually absent; pedicels 5–20 mm long; tepals ovate, $3\text{--}5 \times 1\text{--}1.5$ mm; androphore 0.7–1 mm long; anther head $0.7\text{--}1 \times 1\text{--}1.5$ mm. Fruit valves 15–30 mm long, 3–5 mm wide. Seeds fusiform, c. 2 mm long papillate at the centre. **Indumentum** absent from stems and uppersurface of leaves; lower leaf and pitchers with scattered red sessile glands 0.1 mm diam.; pitchers also with minute scurfy brown stellate hairs, particularly in a band immediately below the peristome; inflorescence completely covered, from base of peduncle to the pedicels and ovary in appressed, thick coppery, $\pm$ simple hairs 0.1–0.3 mm long. **Colour** of pitchers green, red, or green mottled with red, rarely black-purple. Flowers variously described as white, green, light red or brown.

Specimens Examined: Sarawak, Samarahan Division, Kota Samarahan, Universiti Malaysia Sarawak, Jalan Kapur Roadside, peat swamp forest, Dec 2019, *Nabilah Huda et al.*, NH0005 (Herbarium Universiti Malaysia Sarawak); Kuching Division, Bau, Gunung Poing, near limestone area, November 2019, *Nabilah Huda et al.*, NH0001 (Herbarium Universiti Malaysia Sarawak); Matang, Matang-Sampadi Roadside, kerangas disturbed areas, 8 Mar 2020, *Nabilah Huda et al.*, NH0015; NH0021 (Herbarium Universiti Malaysia Sarawak); Bako NP, Kerangas forest, 27 Sep 2020, *Nabilah Huda et al.*, NH0032 (Herbarium Universiti Malaysia Sarawak); Bau, Banjaran Undan, mixed dipterocarp forest, 19 Dec 2020, *Nabilah Huda et al.*, NH0028 (Herbarium Universiti Malaysia Sarawak); Bau,

roadside near the Aquilaria Plantation, peat swamp forest, 3 Dec 2020, *Nabilah Huda et al.*, *NH0027* (Herbarium Universiti Malaysia Sarawak).

Etymology: The species name was originated from Latin word, *gracilis* is referring to the shape of the pitcher which means slender, thin and graceful.

Distribution: Borneo, Peninsular Malaysia, Singapore, Thailand, Sumatra, and Sulawesi.

Habitat and Ecology: *N. gracilis* usually grow in the damp and sun exposed area. It also can be found creeping on the soil among the *Gleichenia* species and also climbing onto the associated plants such as *Ploiarium*. It is a lowland species that grows in the peat swamp forest, kerangas forest, sandstones, and disturbed areas.

Conservation Status: *Nepenthes gracilis* has been categorised as Least Concern based on the assessment for the IUCN Red List 2014 (Clarke, 2018d). The population trend of this species is increasing and can be found in wide variety of habitats and locations.

5. *Nepenthes hirsuta* Hook. f.

Nepenthes hirsuta Hook.f. in A.DC, Prodr. 17 (1873) 99; Danser, Bull. Jard. Bot. Buitenzorg III, 9 (1928) 306, f. 8; Phillipps & A.L. Lamb, Nature Malaysiana 13, 4 (1988) 16; Pitcher Plants of Borneo (1996) 92, f. 50; Jebb & Cheek, Blumea 42 (1997) 47; Clarke, *Nepenthes* of Borneo (1997) 93, f. 61-62.

Type specimen: Low s.n. (holo K), Borneo, Lawas River.

Synonym: *Nepenthes hirsuta* var. *glabrata* Macfarl., *N. hirsuta* var. *typica* Macfarl., *N. leptochila* Danser.

Description: Terrestrial climber 1-4 m tall. **Stem** terete, 3.8–4.2 mm diam., internodes of short stems 5–2 mm long, of climbing stems 4.8–5.2 mm long. **Leaves** coriaceous, subsessile; leaves of short shoots and rosettes oblanceolate, 3–19 × 1–4.3 cm, the lowermost 1/8-1/10 narrowed to a winged, poorly defined petiole, leaf bases shortly sheathing, amplexicaul, encircling the entire stem circumference; leaves of climbing shoots oblanceolate, 14.5–21 × 4.6–5.7 cm, tapering to an acute apex, the basal 1/5-1/6 (i.e. up to 4-5 cm long), usually narrowed to c. 1 cm wide and resembling a winged petiole, base sheathing, encircling c. 1/3 the stem circumference. Longitudinal nerves 3-5 on each side of the midrib in the outer half, conspicuous above and below. Pennate nerves numerous, held at ± 90° from the midrib, inconspicuous, not reaching the marginal nerve. **Lower pitchers** ovoid or ellipsoid, tapering into a shortly cylindrical upper part, 6–18 × 3.6.5 cm, with two fringed wings 2.5 – 3 mm broad, the fringed elements 3–6 mm long; mouth ovate, 2.2–4 × 1.2–1.5 cm apex long-acuminate, oblique; the peristome cylindrical to slightly flattened, 1.5–4 mm wide, with pronounced ribs 0.25–0.5 mm apart, 0.1-0.2 mm high, outer edge rarely slightly sinuate in largest pitchers, inner surface with broad stiff, slightly forward

curved teeth c. 1 mm long; column short and broad, the peristome teeth expanded in two protuberant ridges; lid broadly to narrowly ovate or elliptic, 1.5–4 × 1.4–2.5 cm, apex rounded, base shallowly cordate, lower surface without appendages, with several large circular or elliptic crater-like glands along the midline c. 0.5 mm long and numerous smaller, circular ones c. 0.1 mm diam., towards the margin, absent at the edge; spur simple 4–15 mm long. **Upper pitchers** as the lower, cylindrical, smaller, rarely ovoid-cylindrical or infundibuliform-cylindrical, 4–13 × 2–3.5 cm, with wings 0.5–4 mm wide, usually fringed, the fringed elements up to 1.5 cm long, 3–4 mm apart; peristome 2–4 mm wide; lid ovate or ovate-oblong, 1.5–2.2 × 1–1.5 cm. **Indumentum** of stems, lower surface of midribs and inflorescences densely, less usually feebly, substrigose to pilose, with fragile, but not caducous, brown, subappressed, stiff, simple (rarely a few 1–3-branched) hairs 0–2 mm long, hair bases swollen; lower leaf blade with sessile red glands very sparsely scattered with patent simple hairs c. 0.5 mm long. **Colour** of lower pitchers green or grey-green splashed with red; upper pitchers always green.

Specimens Examined: Sarawak, Kuching Division, Bau, Banjaran Undan, Stenggang Dam trail, kerangas forest, 19 Dec 2022, *Nabilah Huda* et al., *NH0030*; *NH0031*; *NH0036* (Herbarium Universiti Malaysia Sarawak); Banjaran Undan, Sepadah Dam Trail, kerangas forest, 3 April 2023, *Nabilah Huda* et al., *NH0039*; *NH0040*; *NH0041*; *NH0042*; *NH0046* (Herbarium Universiti Malaysia Sarawak).

Etymology: The epithet name of this species is referring to the dense brown indumentum that are formed in most part of the plants. The name *hirsuta* was derived from Latin word, *hirsutus* = bristly or hairy.

Habitat and Ecology: Lowland species that occurs at least 200 to 1100 m a.s.l. It can be found in Kerangas forest, submontane forest, or sandstone.

Distribution: Endemic to Borneo. Sarawak, Sabah, Brunei, and Kalimantan.

Conservation Status: The population trend of *N. hirsuta* is consider as stable, and therefore, this species is categorised as Least Concern (LC) based on the IUCN Red List 2014 (Clarke, 2018e).

6. *Nepenthes hispida* Beck

Nepenthes hispida Beck, Wiener III. Gart. -Zeitung 20 (1895) 187; Jebb & Cheek, Blumea 42 (1997) 48, f. 5; Clarke, *Nepenthes of Borneo* (1997) 94, f. 63.

Type specimens: Burbidge s.n. (lecto W sh. 55649; iso K, W), Sarawak, Lawas River, 2000–3000 ft.

Synonym: *Nepenthes hirsuta* auct. non Hook. f.

Description: Terrestrial climber to c. 5 m tall. **Stem** terete, 2–5 mm diam., internodes of climbing stems 4.5–6.5 cm long. **Leaves** coriaceous, sessile, blade oblanceolate to oblong, sometimes narrowly so; 5–10 × 1–3 cm, apex shortly acuminate to obtuse, often unequal, not peltate, base decurrent-amplexicaul, extending down the stem by c. 1 cm, and clasping it by 9/10 its diameter, the wings short, but 4–6 mm broad, and almost meeting opposite the axil. Longitudinal nerves 3 on each side of the midrib in the outer half, from the leaf base. Pennate nerves apparently few, patent, inconspicuous. **Upper pitchers** cylindrical, ovoid-ellipsoid in the lower half, the upper half subcylindrical, tapering slightly to the mouth, 3.5–10 × 2.5–3, with two fringed wings near mouth, 1–3 mm wide, fringed elements sparsely or lacking, c. 2 mm long, 1–2 mm apart; mouth ovate, oblique, slightly concave; peristome rounded, 0.5–1.2 mm wide, not sinuate, ribs c. 0.25 mm apart, the inner margin with teeth c. 1 mm long; lid ovate-elliptic, 2.2–3 × 1.5–2 cm, apex rounded, base truncate to slightly cordate, lower surface lacking appendages, with numerous circular, crater-like glands c. 0.15 mm wide, those on the midline, larger, elliptic, to 0.35 mm long; spur c. 5 mm long, entire. Indumentum as *N. hirsuta*, but denser and longer, of erect, slightly forward pointing, mostly

simple, dark coppery, bristle-like hairs 1.5-4 mm long, persistent and highly conspicuous on the stem, tendril, sparser on the abaxial of the leaf blade. **Colour** of pitchers green, flecked with red on the inner surface at the upper half, peristome green.

Specimens Examined: Sarawak, Kuching Division, Bau, Banjaran Undan, Sepadah Dam trail, 3 April 2023, *Nabilah Huda* et al., *NH0047* (Herbarium Universiti Malaysia Sarawak); Kuching, Bako NP, 29 March 2023, *Nabilah Huda* et al., *NH0048* (Herbarium Universiti Malaysia Sarawak).

Etymology: The scientific name of *hispida* was derived from a Latin word, *hispidus* means bristly.

Habitat and Ecology: Lowland habitats at shady forest of kerangas, or steep sandstone ridges.

Distribution: Borneo (Sarawak and Brunei only).

Conservation Status: The IUCN Red List assessment categorised *Nepenthes hispida* as lower risk or conservation dependent in year 2000 (Clarke et al., 2000).

7. *Nepenthes mirabilis* (Lour.) Druce

Nepenthes mirabilis (Lour.) Druce, Rep. Exch. Cl. Br. Id. (1916) 637; Merr., Interpr. (1917) 242; Danser, Bull. Jard. Bot. Buitenzorg III, 9 (1928) 330; Sh. Kurata, *Nepenthes* of Mt Kinabalu, Sabah (1976) 56; Tamin & M. Hotta in M. Hotta, Diversity and Dynamics of Plant Life in Sumatra (1986) 88; Jebb, Science in New Guinea 17 (1991) 32, f. 16; J.H. Adam & Wilcock, Mai. Nat. J. 46 (1992) 76; Philipps & A.L. Lamb, Pitcher Plants of Borneo (1996) 109, f. 57; Jebb & Cheek, Blumea 42 (1997) 63; Clarke, *Nepenthes* of Borneo (1997) 105, f. 70 & 71; J.H. Adam & Wilcock, Sarawak Mus. J. 50 ('1996', 1998) 160. — *Phyllamphora mirabilis* Lour., Fl. Cochinch. 2 (1790) 606. — *Nepenthes phyllamphora* Willd., Sp. PL, ser. 4, 2 (1805) 874. — Type: Loureiro s.n. (Pn.v.), Vietnam, near Hue. *Nepenthes phyllamphora* Willd., Sp. PL, ser. 4, 2 (1805) 874. — Type: Loureiro s.n. (Pn.v.), Vietnam, near Hue.

Type specimen: Loureiro s.n. (Pn.v.), Vietnam, near Hue.

Synonym: *Cantharifera* Rumph. *Nepenthes moluccensis* Oken, *N. phyllamphora* var. *platyphylla* Blume, *N. macrostachya* Blume, *N. fimbriata* Blume, *N. fimbriata* var. *leptostachya* Blume, *N. kennedyana* F. Muell., *N. echinostoma* Hook. f. — *N. mirabilis* var. *echinostoma* J.H. Adam & Wilcock, *N. phyllamphora* var. *macrantha* Hook. f., *N. bernaysii* F.M. Bailey, *N. obrieniana* Linden & Rodigas, *N. jardinei* F.M. Bailey, *N. rowanae* F.M. Bailey, *N. albolineata* F.M. Bailey, *N. moorei* F.M. Bailey, *N. alicae* F.M. Bailey, *N. cholmondeleyi* F.M. Bailey, *N. pascoensis* F.M. Bailey, *N. armbrustae* F.M. Bailey, *N. garrawayae* F.M. Bailey, *N. tubulosa* Macfarl., *N. beccariana* Macfarl., *N. phyllamphora* var. *pediculata* Lecomte, *N. mirabilis* var. *biflora* J.H. Adam & Wilcock, *N. phyllamphora* auct. non Willd., *N. distillatoria* auct. non L., *N. phyllamphora* auct. non Willd., *N. burbidgeae* Hook. f. ex Burb.

Descriptions: Terrestrial shrub or climber to 10 m tall. **Climbing stems** woody, terete, 6–7 mm diam., internodes 1.5–5 cm long, axillary buds inconspicuous. **Leaves** thinly chartaceous, rarely membranous or thickly chartaceous, petiolate, leaves of rosettes and short stems lanceolate or oblong, apex acuminate, not peltate, margin fimbriate, fimbriae c. 2 mm long, petiole base sheathing, leaves of climbing stems lanceolate–oblong, and obovate, 6.7–16.9 × 3–6 cm, apex acute, margin entire, petiole canaliculate, rarely slightly winged, 2.5–4.25 cm long, clasping the stem by 1/2 its circumference. Longitudinal nerves originating from along the midrib, 4–8 on each side of the midrib, scattered throughout lamina, conspicuous. Pennate nerves numerous, curving towards margin, to almost perpendicular, forming distinct rectangles with longitudinal nerves, conspicuous. **Lower pitchers** ovoid in lower half, cylindrical in upper half, 8.5–14 × 3.3–4.5 cm, with 2 fringed wings 2–3 mm wide, 1.5 – 2.5 mm long, c. 1.5 mm apart; mouth elliptic or broadly ovate, slightly oblique, straight, 2.3–2.7 × 1.6–2.4 cm; peristome slightly to conspicuously flattened, 2–8 mm broad, ribs c. 0.1 mm apart, conspicuous, outer edge of peristome entire, inner lacking conspicuous teeth; lid held close to the mouth, elliptic, rarely orbicular, 2.6–4.4 × 2.2–3.4 cm, apex rounded or slightly retuse, base rounded or truncate, very slightly vaulted, with 2 prominent veins above, lower surface lacking appendages, but often with a slight pucker on the midline, c. 1/8 from apex, nectar glands dense, evenly spread, orbicular, thinly-bordered to volcano-like, c. 0.2 mm, smallest towards margin, larger and slightly longitudinally elliptic, c. 0.25 mm long, along midline; spur flattened, 4–5 long, c. 1 mm wide, entire or rarely divided into 3 or more branches. **Upper pitchers** gradually originating from tendril, wholly subcylindrical and slightly laterally flattened, or slightly infundibuliform at base, cylindrical above, with distinct 'hipped' point 1/3–1/2 from the base, 10.2–13.5 × 1.5–5.5 cm, with 2 ridges; mouth, peristome and lid more or less as lower

pitcher; spur usually entire, dorsiventrally flattened, c. 5 mm long, c. 1 mm wide, apex rounded. **Male inflorescence** scented of mice droppings or pandan leaves, 26–46.5 cm long, 2–3.5 cm diam.; peduncle 13–26.5 cm long; partial peduncles 1-flowered (rarely 2-flowered); bracts absent; pedicels 4–15 mm long; tepals four, broadly elliptic, c. 2 × 5 mm; androphore c. 2 mm long; anther head 1–1.5 × 1.5–2 mm. **Indumentum** usually inconspicuous, of fine whitestellate or sparingly branched, crinkled, sometimes with arachnoid hairs 1–3 mm long, soon falling and usually only visible on youngest growth and inflorescence, androphore glabrous; sessile red glands c. 0.1 mm diam. present on stem; scattered nectar glands present on stem. **Colour** of pitchers green rarely streaked or wholly suffused with red.

Specimens Examined: Sarawak, Samarahan Division, Kota Samarahan, Universiti Malaysia Sarawak, Jalan Kapur roadside, peatswamp forest, 30 Nov 2019, *Nabilah Huda* et al., *NH001*; *NH0002* (Herbarium Universiti Malaysia Sarawak); Kuching Division, Matang, Matang-Sampadi Roadside, disturbed kerangas areas, 8 Mar 2020, *Nabilah Huda* et al., *NH0014*; 23 Oct 2020, *Nabilah Huda* et al., *NH0022*; 23 Jan 2022, *Nabilah Huda* et al., *NH0050* (Herbarium Universiti Malaysia Sarawak); Bau, Banjaran Undan, Foothill trail, Kerangas forest, 15 Dec 2020, *Nabilah Huda* et al., *NH0029* (Herbarium Universiti Malaysia Sarawak).

Etymology: The epithet name *mirabilis* was derived from a Latin word means wonderful.

Habitat and Ecology: Grows in wide range of habitat, normally in the open or wet lowland areas such peat swamp forest, Kerangas forest, and disturbed areas.

Distribution: Borneo, Peninsular Malaysia, Sumatra, Sulawesi, Java, New Guinea, Thailand, Vietnam, Philippines, Maluku, China, Macau, Hong Kong, Palau Island, and Australia.

Conservation Status: *Nepenthes mirabilis* is listed as Least Concern species based on the IUCN Red List assessment in 2014 by Clarke (2014). This species is the most widespread species in the genus *Nepenthes* and the population is increasing.

8. *Nepenthes mirabilis* var. *echinostoma* (Hook. f.) Adam, J. H. & Wilcock

Nepenthes mirabilis var. *echinosotoma* Adam, J. H., & Wilcock. (1992). In: Malaysian Nat. J., 46(2): 81.

Type specimens: Beccari 121 (FI n.v., K), Borneo, Sarawak, Kuching.

Synonym: *Nepenthes mirabilis* (Lour.) Druce., *N. echinostoma* Hook. f.

Descriptions: Terrestrial climber up to 5 m tall. **Stem** woody, cylindrical, 6.7–11.4 mm diam., internodes 1–8 cm long. **Leaves** papery, slightly leathery, petiolate, blade oblanceolate, 8.5–32 x 3.5–8 cm, apex acute, slightly acuminate, base slightly cuneate, petiole, 4–8.5 cm, winged, clasping $\frac{1}{2}$ of its circumference, base very slightly deccurent by 4–8 mm. Longitudinal nerves 5 on each side of the midrib and close to the margin. Pennate nerves numerous, usually obscure. Margin entire. Tendril up to 28 cm long, single or double coiled at the middle. **Upper pitcher** wholly cylindrical, slightly laterally flattened, sometimes infundibuliform at the base, ‘hipped’ point at the middle ($\frac{1}{2}$ from the base), 14.5–18.5 × 4–6 cm, with two prominent ridges; mouth ovate-elliptic, 29.62–35.01 mm × 15.1–17.67 mm; peristome slightly flattened, 1–1.5 cm wide, ribs freely formed, attached at the inner base, c. 2–3 mm apart, inner edge with teeth; lid elliptic, rarely orbicular, 3.8–8 cm × 3.2–3.5 cm, nectar gland sparsely distributed on the lower surface of the lid; spur 1 to 2-branched, c. 1 cm. **Indumentum** arachnoid white hairs on the young apical stem, and on the leaves. **Colour** light green spotted with red on the leaves and the pitchers, adaxial midrib reddish pink, stem light brownish green.

Specimen Examined: Sarawak, Kuching Division, Pueh FR, Kerangas forest, March 2021, Meekiong, K. et al., NH0038 (Herbarium Universiti Malaysia Sarawak).

Etymology: The variety name *echinostoma* is a new Latin that was derived from ancient Greek words, *ekhin* = hedgehog or sea urchin, and *stoma* = mouth. This name is referring to the unique characteristic of the peristome in *Nepenthes mirabilis* var. *echinostoma*.

Habitat and Ecology: Lowland area such as peat swamp forest, and kerangas forest.

Distribution: So far, this variety has been recorded from Borneo only, particularly in Sarawak, Sabah, and Brunei.

Notes: *Nepenthes mirabilis* var. *echinostoma* was first discovered in year 1865 by Odoardo Beccari, and then was described as a species, *N. echinostoma* by Joseph Dalton Hooker in year 1873. However, Frederick William Burbidge finally redescribed it as a variety of *N. mirabilis* in year 1882.

9. *Nepenthes nazreeana* sp. nov. ined.

Descriptions: Terrestrial climber up to 3m tall. **Stem** woody, cylindrical, 0.77 – 0.95 cm diam., internodes 3 – 15 cm long. **Leaves** coriaceous, petiolate, blade elliptic-oblongate, 11.0 – 25.0 cm x 5.0 – 8.0 cm, apex obtuse to very slightly truncate, base rounded to slightly truncate, winged petiole, 0.8 – 1.8 cm x 8.5 – 10 cm, clasping $\frac{1}{2}$ of its circumference, base very slightly deccurrent by ca. 0.4 – 0.8 mm. Longitudinal nerves 5 on each side of the midrib and close to the margin, pennate nerves numerous, usually obscure. Margin entire. Tendril up to 28 cm long, single or double coiled at the middle. **Lower pitcher** cylindrical, slightly ovoid at the base, 14–19 x 5–6 cm, with 2 fringed wings, 3–10 mm broad, fringe elements up to 5 mm long, up to 3 mm apart; peristome mouth cordate, ribs c. 5 mm wide, outer edge sinuate, inner edge slightly flattened with very fine teeth, c. 0.1 mm; lid $\pm$ ovate – suborbicular, 3.5–6 cm x 3–5.5 cm, apex $\pm$ retuse – obcordate, base rounded to slightly cordate, appendages presence on the abaxial, glandular, circular–ellipse, ca. 0.1 mm diam., midline slightly pronounced, keel slightly pronounced; spur single, unbranched, 1–1.2 cm long, 2 mm wide, slightly stout, **Upper pitcher** cylindrical at the base up to the upper part with slightly ventricose at the middle, 17.2–18.7 cm x 3.5–4 cm, fringed wings absent; peristome mouth cordate, ribs very fine, 0.5–1 mm wide, outer edge entire and sinuate, inner edge dentate with a very fine teeth, c. 0.1 mm;. **Male inflorescence** developed at the after 4 – 5 leaves from the tip of stem, racemes, up to 26 cm, peduncle ca. 17.4 cm, pedicel ca. 2.2 cm, 2-branched with flowers; flowers up to 250, tepal 4, 5.5–8 mm, orbicular elliptical, rather cupped, staminal column c. 7 mm. **Female inflorescence** developed at the terminal of the plant, up to 12.8 cm long, peduncle 13.2 cm, pedicel 1.9–2 cm long, tepal ovate, c. 6 x 4 mm, apex acute–rounded; fruit immature, c. 7 mm long. **Indumentum** presence on leaves, white hairs long and scattered on the leaves surface when young, very conspicuous on the

midrib, soon the white hair lack when the leaves are fully mature, trichome stellate-slightly fascicle with long arm, 5–7 arms, 150–200 µm long, clavate peltate glandular on the abaxial leaves, c. 33–40 µm × 35–45 µm, broad flower-like peltate eglandular trichome on the adaxial, short stellate on the abaxial of pitcher, 6 – 8 arms, *ca.* 57 – 110 µm. **Colour** of stem whitish brown, leaves light green, greyish green when dried, pitcher light green splashed with red to purplish red colour.

Specimens Examined: Sarawak, Kuching Division, Matang, Matang – Sampadi road, kerangas forest, exposed area by the roadside, rocky and white sandy soil, (1°38'41"N, 110°07'15"E), 23 October 2020, *Nabilah Huda, Meekiong, Mohd Akmal, Umie Naylisa & Athirah Nabihah, NH0012; NH0019*, [Holo: SAR]; *Meekiong s.n.*, [Para: SAR (spirit coll.)]

Etymology: The epithet name is given in honour of Mr. Nazree Ngadi, who is funding the academic and research project and relentlessly support and encourage the author to keep pursue her passion in Botany field.

Habitat and Ecology: Occurs as terrestrial climber on the acidic sandy soil with pH about 6.6 and moisture 8.8% and grow sympatrically with several common *Nepenthes* species which are *N. ampullaria*, *N. gracilis*, *N. mirabilis* and *N. rafflesiana*. Also, this new species grows in secondary bushes at roadside embankment associated with several other species such as *Ploiarium alterniafolium* and *Gleichenia* sp.

Distribution: This species (Figure 4.35) was encountered at Matang - Sempadi/Lundu Roadside (1°38'41"N, 110°07'15"E), Kuching Division, Sarawak at altitude of 52 m above the sea level. So far, the *N. nazreeana* was known from this type of locality only.



Figure 4.35: *Nepenthes nazreeana* sp. nov. ined. insitu. (A) Habitat of the species. (B) The upper pitcher form (C) The lower pitcher form

10. *Nepenthes northiana* Hook. f.

Nepenthes northiana Hook.f., Gard. Chron. II (1881) 717, t. 144 & p. 724 & 725; Danser, Bull. Jard. Bot. Buitenzorg III, 9 (1928) 342; Philipps & A.L. Lamb, Pitcher Plants of Borneo (1996) 119, f. 64; Jebb & Cheek, Blumea 42 (1997) 69; Clarke, *Nepenthes of Borneo* (1997) 113, f. 75.

Type specimen: Curtis s.n. (K), Borneo, Sarawak, Jambusan.

Synonym: *Nepenthes spuria* Beck, *N. nordtiana* Boerl., *N. northiana* var. *pulchra* Hort. ex Macfarl., *N. decurrens* Macfarl.

Description: Terrestrial shrub or climber, 1-4 m tall. **Stems** 3-4 angular-rounded, 0.4-1.5 cm diam., with 4 wings, each c. 5 mm wide, decurrent from the leaf base above and abruptly uniting above the axil below, and on the same side of the stem; short shoots with internodes c. 0.4-1.5 cm long, wings forming a saddle-like shape; climbing shoots with internodes 3-7.5 cm long. **Leaves** coriaceous, sessile to weakly petiolate; leaves of short shoots long elliptic to spatulate, 7.8-49.8 × 2-11 cm, apex acute with tendril peltate by several mm, base attenuate, forming an ill-defined, winged petiolar area 2-4.5 cm wide, clasping the stem for 1/2 its circumference, the wings decurrent, initially sheathing, then patent; leaves of climbing stems narrowly oblong-elliptic, 42-51 × 4.6-6.4 cm. Longitudinal nerves 3 (or 4) on each side of the midrib in the outer half, prominent above and below. Pennate nerves patent, straight, little branched, conspicuous above and below. **Lower pitcher's** recumbent, ellipsoid, 3.5-29.5 × 2.5-6.5 cm, with two fringed wings 5-8 mm wide, the fimbriae c. 4 mm long; mouth oblique, slightly concave, narrowly ovate, 2-12.8 × 0.5-4.2 cm; peristome flattened, with ribs c. 1 mm apart, 5 or 6 striae between each ridge, outer edge of peristome 12-40 mm broad, gradually widening towards the lid, dentate, folded into 12-16 shallow

teeth 3-7 mm long, inner edge appressed to pitcher wall, 5-10 mm wide, the margin with falcate teeth 1 mm long; column absent; lid as large or larger than mouth, held at 45° elevation from mouth, narrowly elliptic, 3–13.5 × 1–5.5 cm, apex rounded, base cordate, lower surface lacking appendages, midrib raised, glands restricted to a thickened area about half the width of the lid and running nearly its length, absent from the midrib, circular or transversely elliptic, bordered, black, 0.2-0.3 mm diam.; spur not seen. **Upper pitchers** cylindrical-infundibulate, 26.5 × 5.4 cm, fringed wings running the length of the pitcher, c. 4 mm wide, fimbriae c. 3 mm long; peristome rounded, 2.5–4 cm wide in the widest part, ribs to 1 mm high; lid 11.45 × 4.6 cm. **Male inflorescence** c. 145 by c. 10 cm; peduncle 33 cm long, 7 mm diam. at base; partial peduncles 2-flowered, 7-22 mm long; bracts 2-3 mm long, absent in some inflorescences; pedicels 17-35 mm long; tepals ovate, 2.5–5.7 × 1.4–2.2 mm; androphore 1–3 mm long; anther head 0.8–1 × 0.9–1 mm. **Infructescence** 21.8 cm long; peduncle 15.8 cm long, 1 cm wide at base, with a pulvinus c. 1.5 cm wide; partial peduncles 6 cm long; pedicels 11.8 cm. Fruits with valves 1.8 by 3.5-4 mm. Seeds filiform, c. 8 × 0.3 mm (probably immature). **Indumentum** of sessile glands on lower surface of leaf blade and outer pitcher and lid intermixed, on the outer pitcher, with simple, patent hairs 0.5 mm long; partial peduncles to lower surface of tepals and ovary fairly densely covered in coppery coloured, 1 or 2 branched appressed hairs 0.3 mm long. **Colour** not seen as the examination are based on the herbarium specimens.

Specimens Examined: Sarawak, Kuching Division, Bau District, Bukit Bidi, limestone hill, 15 Nov 1985, *Yii et al.*, *S50394* (SAR); 19 Oct 1929, *M. & J. Clemens*, *S7456* (SAR); Bukit Kapor, south face, limestone cliffs, 14 Oct 1961, *B.E. Smythies*, *S15244* (SAR); Tai Ton, Tai Ton Limestone Hill, limestone forest, 12 Dec 1975, *P.F Stevens et al.*, *203* (SAR); 18 Nov

1985, *Yii et al.*, S51217 (SAR); Bukit Numpang, limestone slope, 15 Dec 1965, *P. Chai* and *L.H. Seng*, S22862 (SAR), Krokong, Bidi Road, Tai Ton, Gunung Tabal, 24 May 1962, *B.L. Burt* and *P.J.B. Woods*, B1914; 24 March 1999, *Patsipun, Jugah et al.*, S82103 (SAR); Kampung Bidi, limestone forest, 31 Dec 1994, *Johnney et al.*, S70248; S70247 (SAR); Gunung Ropih, limestone summit, 11 Dec 2001, *Shaevy, W., et al.*, SBC2412 (Figure 4.37); SBC2413 (SAR); Gunung Umbut, limestone shoulder, 26 March 2002, *Meekiong, K. et al.*, SBC2708 (SAR); Seburan, 23 Feb 1958, *M.R. Andia*, S9094 (SAR); limestone cliff, 6 May 1962, *J.A.R Anderson*, S15476 (SAR); Gunung Aup, limestone, 9 Oct 2001, *Meekiong, K.*, SBC242 (SAR); Serian Division, Tebedu, Mile 15th, limestone forest, 6 Feb 1985, *Abg. Mokhtar et al.*, S49230 (SAR) (Figure 4.36).

Habitat and Ecology: Occur at the lowland to highland areas, from 40 to 800 m altitude at limestone area.

Distribution: Endemic to Sarawak, especially in the the Bau area of Kuching division, western Sarawak.

Conservation Status: This Sarawak endemic species is considered as Vulnerable (VU) in the IUCN Red List of Threatened Species 2000 (Schnell et al., 2000b).

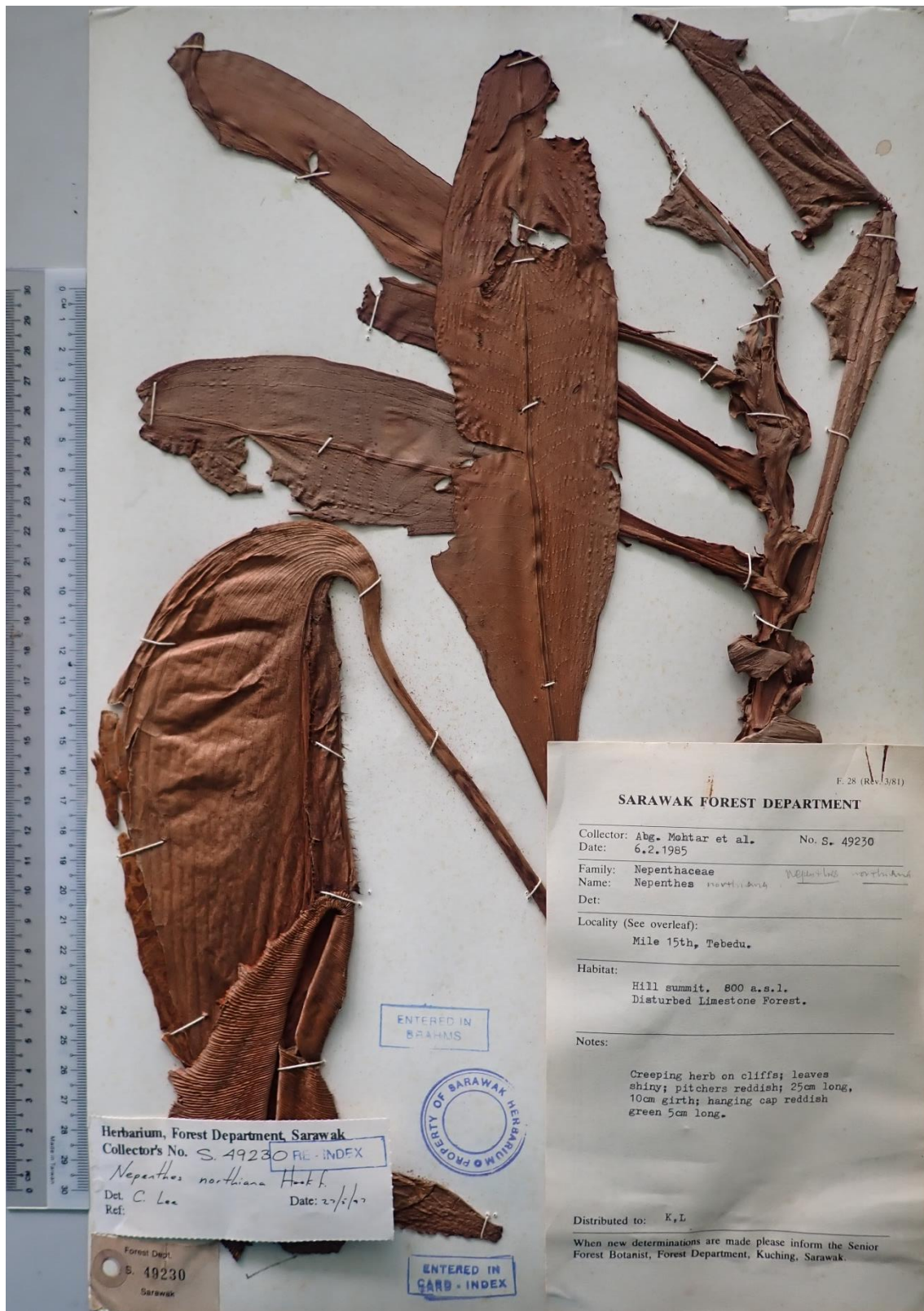


Figure 4.36: Herbarium specimen of *Nepenthes northiana* Hook. f. Borneo, Malaysia, Sarawak, Kuching division, Tebedu, Mile 15th, 6 February 1985, Abg, Mokhtar et al., S49230, SAR



Figure 4.37: Herbarium specimen of *Nepenthes northiana* Hook. f. Borneo, Malaysia, Sarawak, Kuching Division, Bau, Gunung Ropih, 11 Dec 2001, Shaevy et al., SBC2412, SAR

11. *Nepenthes rafflesiana* Jack ex Hook. f.

Nepenthes rafflesiana Jack, Mai. Misc. ex Hook.f., Comp. Bot. Mag. 1 (1835) 270; Danser, Bull. Jard. Bot. Buitenzorg III, 9 (1928) 357; Shivas, Pitcher Plants of Peninsula Malaysia & Singapore (1984) 39; Tamin & M. Hotta in M. Hotta, Diversity and Dynamics of Plant Life in Sumatra (1986) 90; Philipps & A. L. Lamb, Nature Malaysiana 13,4(1988) 14; Pitcher Plants of Borneo (1996) 123, f. 66-68; Jebb & Cheek, Blumea 42 (1997) 75; Clarke, *Nepenthes* of Borneo (1997) 116, f. 77-80. —Type: Jack s.n. (lecto SING), Singapore.

Type specimen: Jack s.n. (lecto SING), Singapore.

Synonym: *Nepenthes raflesea* Hort., *N. rafflesiana* var. *nivea* Hook. f., *N. rafflesiana* var. *glaberrima* Hook. f., *N. rafflesiana* var. *insignis* Mast, *N. rafflesiana* var. *nigro-purpurea* Mast, *N. hookeriana* H. Low ex Becc., *N. rafflesiana* var. *minor* Becc., *N. rafflesiana* var. *typica* Beck, *N. rafflesiana* var. *ambigua* Beck, *N. rafflesiana* var. *elongata* Hort., *N. sanderiana* Burb., *N. hemsleyana* Macfarl., *N. rafflesiana* var. *alata* J.H. Adam & Wilcock, *N. hookeriana* auct. non Lindl., *N. rafflesiana* auct. non Jack, *N. rafflesiana* var. *excelsior* (Lindl.) Beck, *N. rafflesiana* var. *longicirrhosa* auct. non: Tamin & M. Hotta

Descriptions: Terrestrial climber 2–6 m tall. **Stems** terete, those of short stems and rosettes 7–14.5 mm diam., internodes 1–3.5 cm long; climbing stems 6.9–10.27 mm diam., internodes 4.5–7.5 cm, axillary buds inconspicuous. **Leaves** papery, distinctly petiolate, leaves of short stems narrowly oblong, 9.2–27.2 × 2.3–6.8 cm, apex acute or slightly acuminate, base abruptly acute or attenuate; leaves of climbing stems generally smaller, 10.5–18.4 × 5–5.5 cm; petiole canaliculate, 3–9.5 × 0.5–1 cm (lower leaves), 10.5–18.4 × 5–5.5 cm (upper leaves), the base, in short stems/rosettes, sheathing the stem and clasping it for 2/3–3/4 its circumference, in climbing stems, neither sheathing nor winged, clasping the

stem for c. 1/2 its circumference. Longitudinal nerves 3–4 on each side of the midrib, inconspicuous above. Pennate nerves usually patent, nearly reaching the margin, rarely branched, inconspicuous. **Lower pitchers** broadly ovoid to subglobose, or ovoid or narrowly ovoid, 12–25 × 4–7 cm, with two fringed wings, 1–3 cm wide, widest at the base, fringed elements 4–6 mm long; mouth oblique or horizontal, strongly concave, rising gradually at the rear and tapering to form a more or less distinct column 3–5 cm high and 1–2 cm deep, column apex swollen, the inner surface beset with protruding teeth 3–5 mm long; some pitchers with the mouth horizontal, flat, forming a 90° angle with the vertical column; peristome subcylindrical, 8–15 mm wide, but sometimes slightly flattened in the largest pitchers, ribs 0.2–0.5 mm apart, outer edge entire, inner edge about twice to thrice as long as the outer, with straight, conspicuous teeth, 2–3 mm long; lid orbicular, broadly or narrowly ovate to long elliptic, the first in the smaller globose pitchers, the latter in the largest, narrowly ovoid pitchers, 4.4–9 × 3.5–9 cm, apex rounded, truncate or retuse, base shallowly cordate or rounded, lower surface lacking appendages, with two prominent main veins diverging from the base, nectar glands conspicuous, circular, narrowly bordered, 0.3–0.5 mm diam., scattered in a band around the periphery; spur 1.5–2.7 cm long, bifurcate at the apex. **Upper pitchers** infundibulate or narrowly infundibulate, rarely subcylindrical, 13–18.5 × 3–6 cm, lacking fringed wings but with two ridges, mouth oblique, more or less straight, usually rising abruptly at the front, at the rear with a short stout column 1–3 cm high, as in the lower pitchers, peristome cylindrical, 2–8 mm wide, ribs c. 1 mm apart, outer edge entire, inner edge with broad short teeth c. 1 mm long; lid broadly or narrowly ovate, rarely orbicular, elliptic or obovate, 4.5–8.7 × 4.5–8.8 cm, apex rounded, truncate, or slightly emarginate, base obtuse to slightly cordate, lower surface lacking appendages, nectar glands conspicuous in a dense band around the periphery, 0.7–0.8 mm diam., sometimes containing

3 or 4 smaller nectar glands; spur, usually entire c. 2 cm. **Male inflorescence** 18.9 – 45 long, 3.5–4 cm diam.; peduncle 6–12 cm long, partial peduncles 1-flowered, rarely mostly 2-flowered, 80–100 flowers; bracts usually absent; pedicels 12–15 mm; tepals elliptic, c. 5 × 5 mm; androphore c. 5 mm long; anther head c. 1.5 × 2.5 mm. **Infructescence** 14 cm long; peduncle 12 cm long, 3.5 mm diam. at the base. Fruits with stipe 4–8 mm long, valves 32 - 50 × 6–10 mm. Seed filiform. **Indumentum** of stems, midribs, lower surface of the leaf blade and inflorescences from base of peduncle to lower surface of the tepals white or grey arachnoid, lower leaf surface with minute white stellate hairs; pitcher surface with red sessile glands c. 0.1 mm diam., sometimes with short red simple patent hairs 0.1–0.2 mm long; inflorescence sometimes with admixture of semi-patent brown hairs 0.3 mm long; androphore glabrous. **Colour** of lower surface of the leaf blade drying brown, upper often yellowish green, stem white. Live lower pitchers generally white, strongly mottled with purplish red, rarely pure white, or white flushed pink; upper pitchers pale green, with peristome striped yellow, green and red; inflorescence with red or brown-red tepals.

Specimens Examined: Sarawak, Kuching Division, Kuching, Mount Santubong NP, Loop trail, kerangas forest, 8 Mar 2023, *Nabilah Huda* et al., *NH0006*; *NH0007* (Herbarium Universiti Malaysia Sarawak); Kuching, Bako NP, Kerangas forest, 27 Sep 2020, *Nabilah Huda* et al., *NH0018* (Herbarium Universiti Malaysia Sarawak); Matang, Matang–Sampadi roadside, kerangas disturbed areas, 8 Mar 2023, *Nabilah Huda* et al., *NH0013*; *NH0016*; 23 Oct 2020, *Nabilah Huda* et al., *NH0020*; *NH0024*; *NH0025*; 23 Jan 2022, *Nabilah Huda* et al., *NH0052* (Herbarium Universiti Malaysia Sarawak); Bau, Banjaran Undan, Stenggang Dam trail, kerangas forest, 19 Dec 2020, *Nabilah Huda* et al., *NH0053* (Herbarium Universiti Malaysia Sarawak); Sepadah Dam trail, kerangas forest, 3 April 2021, *Nabilah*

Huda et al., NH0054 (Herbarium Universiti Malaysia Sarawak); Foothill trail, Kerangas forest 3 April 2021, *Nabilah Huda et al., NH0055* (Herbarium Universiti Malaysia Sarawak).

Habitat and Ecology: Can be found grows in Kerangas forest and peat swamp forest at the lowland altitudes between sea level to 500 m a.s.l.

Distribution: Sumatra, Singapore, Peninsular Malaysia, and Borneo.

Etymology: The scientific name of *N. rafflesiana* was named after Sir Stamford Raffles, who once served as a British Governor of the Dutch East Indies and the Lieutenant-Governor of Bencoolen.

Conservation Status: Least Concern as assessed by the IUCN Red List in 2014 and published by Clarke (2018f). *Nepenthes rafflesiana* is one the common species in the genus and widespread in many habitats and localities.

12. *Nepenthes reinwardtiana* Miq.

Nepenthes reinwardtiana Miq., Pl. Jungh. (1852) 168; Danser, Bull. Jard. Bot. Buitenzorg III, 9 (1928) 363; Sh. Kurata, *Nepenthes* of Mt Kinabalu, Sabah (1976) 65, t. 22; Tamin & M. Hotta in M. Hotta, Diversity and Dynamics of Plant Life in Sumatra (1986) 93; J.H. Adam & Wilcock, Edinb. J. Bot. 50 (1993) 99; Philipps & A.L. Lamb, Pitcher Plants of Borneo (1996) 132, f. 71; Jebb & Cheek, Blumea 42 (1997) 78; Clarke, *Nepenthes* of Borneo (1997) 123, f. 84-86; J.H. Adam & Wilcock, Sarawak Mus. J. 50 ('1996', 1998) 161. —Types: Junghuhn s.n. (sh. 00274, U n.v.), Sumatra, Batak region, Pager-utang, 600 m, Sept. 1840. Or Junghuhn s.n. (sh. 00273, U n.v.), Sumatra, Batak region, Simur-wasos, 1350 m. *Nepenthes reinwardtii* Hook.f., Trans. Linn. Soc.

Type specimens: Junghuhn s.n. (sh. 00274, U n.v.), Sumatra, Batak region, Pager-utang, 600 m, Sept. 1840, or Junghuhn s.n. (sh. 00273, U n.v.), Sumatra, Batak region, Simur-wasos, 1350 m.

Synonym: *Nepenthes reinwardtii* Hook. f., *N. reinwardtiana* var. *samarindaiensis* J.H. Adam & Wilcock.

Descriptions: Terrestrial or epiphytic shrub or climber 4 m tall. **Stem** triangular, rarely $\pm$ rounded, 3.5 – 4 mm diam., the corners rounded or 2 with wings up to 3 mm broad. **Leaves** chartaceous, sessile; basal rosette leaves not known; climbing leaves with blade oblong–lanceolate, 7.1–14 $\times$ 1.9–2.4 cm, apex acute, base distinctly attenuate, or narrowing slightly at the stem, decurrent as wings by up to 8.5 cm, rarely only slightly decurrent into the stem by 1–5.5 cm, clasping the stem for 1/2 its circumference. Longitudinal nerves conspicuous, 2 on each side of the midrib, usually in the outer third, ascending from the midrib. Pennate nerves, ascending from the midrib, sometimes extending into longitudinal nerves, inconspicuous. **Upper pitchers** ellipsoid in the basal half, slightly ventricose, gradually

becoming slightly constricted towards the subcylindrical upper half but wider below the mouth, 2.2–3 cm wide at the base, 1.5–2.3 cm wide at the waist, 1.5–2.7 cm wide at the mouth; with two ridges to 0.1 cm broad lacking fringing elements; the inner pitcher surface glaucous, with 2 conspicuous darker eye-like dots 2–5 mm wide set symmetrically c. 1 cm apart on the dorsal wall of the pitcher more or less level with the front of the peristome; lid 2.3–3 × 1.7–2.3 cm. **Male inflorescence** raceme, length unknown, peduncle 7.5 cm long, 3 mm diam. at base; partial peduncles 2-flowered, 0.2–1 cm long; bracts absent; pedicels 1.5 – 2.5 cm long; tepals ± elliptic 2–3 × 2.5 mm; androphore 5–7 mm long; anther head 0.7–1 × 1.5 mm. **Indumentum** absent from the stem and leaves, rarely present on the pitcher just below the peristome; inflorescence covered, sometimes only sparsely, with appressed brownish hairs c. 0.2 mm long that extend from the rhachis to the lower surface of the tepals, the androphore. **Colour** of pitcher light green, rarely suffused red or with red spots; flowers reddish black.

Specimen Examined: Sarawak, Kuching Division, Bako NP, kerangas forest, 25 March 2022, *Nabilah Huda et al.*, *NH0051* (Herbarium of Universiti Malaysia Sarawak).

Etymology: The specific epithet name was given after Sir Caspar Georg Carl Reinwardt, a Dutch botanist by Miquel who found the Bogor Botanical Garden in Indonesia.

Habitat and Ecology: Frequently occurs in lowland habitats, but occasionally can be found in the highland areas, sea level to 1600 m altitude. Often grow epiphytically on the branches of other plants, or growing terrestrially in peat swamp forest and open areas such as coastal sandstone cliff, and disturbed areas, e.g. roadside embankments, disturbed keranags forest.

Distribution: Borneo and Sumatra

Conservations Status: Listed as Least Concern (LC) species based the IUCN Red List assessment 2014 (Clarke et al., 2000).

13. *Nepenthes tentaculata* Hook. f.

Nepenthes tentaculata Hook.f. in A.DC., Prodr. 17 (1873) 101; Danser, Bull. Jard. Bot. Buitenzorg III, 9 (1928) 379; Sh. Kurata, *Nepenthes* of Mt Kinabalu, Sabah (1976) 69; Phillipps & A.L. Lamb, Pitcher Plants of Borneo (1996) 138, f. 74; Jebb & Cheek, Blumea 42 (1997) 85; Clarke, *Nepenthes* of Borneo (1997) 129, f. 89 & 90; J.H. Adam & Wilcock, Sarawak Mus. J. 50 ('1996', 1998) 161.

Type specimen: Lobb 83 (lecto K), Borneo, Sarawak, 810 m, 1857.

Synonym: *Nepenthes tentaculata* var. *imberbis* Becc., *N. tentaculata* var. *tomentosa* Macfarl.

Descriptions: Terrestrial climber to 4 m tall, but often climbing only rarely and existing largely as gregarious rosettes c. 10 cm tall arising from creeping stems. **Stems** sharply to rounded 4-angular, 1.5–5 mm diam., internodes in rosette shoots c. 4–15 mm; climbing stems with internodes 2–10 cm long, often with conical axillary buds 1.5 by 1.5 mm inserted 3–3.5 mm above the axil. **Leaves** chartaceous, sessile, those of rosettes and short stems elliptic-oblong, 4–6.5 × 1–2.4 cm, apex acute often inconspicuously peltate, base amplexicaul, subperfoliate, shortly decurrent down the stem by 2–4 mm; leaves of climbing stems elliptical-oblong, oblanceolate-oblong, 3–13.3 × 1.5–3 cm, base slightly cordeate, perfoliate or subperfoliate, clasping 2/3 of the stem circumference, decurrent down the stem by 5 – 15 mm. Longitudinal nerves 2 or 3 on each side of the midrib, usually in the outer third, prominent above and below. Pennate nerves sparse, patent, branching and anastomosing, inconspicuous. **Lower pitchers** ovoid or broadly subcylindrical, 4–6.5 × 1–2.4 cm, with two fringed wings c. 2 mm wide, fringed elements filiform, 2–5 mm long, 1–1.5 mm apart; mouth concave, narrowly ovate-rhombic, 1–1.8 × 0.8–1.6 cm, peristome

small, cylindrical, 1–3 mm diam., outer edge not sinuate, inner edge entire; column absent; lid ovate to elliptic-rhombic, $1-2 \times 0.6-1.5$ cm, apex rounded, base rounded or shallowly cordate, upper surface bearing 'tentacles' i.e. thick multicellular simple hairs c. 2 mm long as extensions of the nerves from the marginal 2 mm, lower surface lacking appendages, midrib pronounced as a low keel c. 0.1 mm high, nectar glands not seen or inconspicuous; spur a fascicle of 3-branches 5-10 mm long, each usually dichotomously branched about 1/3 the length from the apex. **Upper pitchers** cylindrical or with a narrowly ovoid base tapering gradually to a cylindrical apex, $5-15.6 \times 1-3$ cm, usually with fringed wings c. 1 cm wide, fringe elements 2–10 mm long; mouth in the larger pitchers sinusoidal from the side view: the front and rear parts much more steeply sloping than at the middle, $2-4 \times 1.8-3.5$ cm; lid ovate, narrowly ovate-elliptical, $2-4.4 \times 1-2$ cm. **Male inflorescence** patent, 25.5–30 cm long; peduncle 12.8–13.0 cm long, 0.75–1.5 mm wide at the base; partial peduncles 1-flowered; bracts absent; pedicels up to 10 mm, often curved; tepals oblong, $1.4-1.7 \times 0.5-1$ mm, apex obtuse; androphore 0.5–1 mm long; anther head c. 1×1 mm. **Infructescence** 21 – 27 cm long; peduncle 14.3–15.8 cm long; fruits with valves $24-40 \times 2-3$ mm. Seeds fusiform, 1.5–2.2 cm long. **Indumentum** of sessile glands on stems, lower leaf blade, outer pitcher, upper and lower lid, and peduncle; rhachis, pedicels and lower tepals moderately densely hairy with simple hairs c. 0.2 mm long; upper surface of lid with 'tentacles'. **Colour** not seen as the examination were based on herbarium specimens.

Specimens Examined: Sarawak, Kuching Division, Mt. Santubong NP, mossy forest, 1927, *Hewitt*, *Hewitt Series* 751(SAR); Apr 1961, *B.E. Smythies*, S15326 (SAR); Kubah NP, Mt. Serapi, summit ridge, Apr 1961, S13142 (SAR); Bau, Bungo Range, moss forest, Oct 1957, *E.F Brunig*, S7632; S9504 (SAR); Lundu, Gunung Berumput, Aug 1960, S13153 (SAR)

(Figure 4.38); Gunung Kanyi, submontane mossy forest, Apr 1984, *S47331* (SAR) (Figure 4.39); Sri Aman Division, Lubok Antu. Mt. Tiang Laju, June 1906, *Hewitt, Hewitt series 369* (SAR); Lingga, March 1913, *Sarawak Museum series 355* (SAR).

Habitat and Ecology: Grows in clumps of *Sphagnum* moss or on peaty soils in the mossy forest, and can be found on sand, and ultramafic substrates as well. Highland species that occurs at the altitude 800 to 2000 m a.s.l.

Distribution: Borneo (Sabah, Sarawak, Brunei, and Kalimantan), and Sulawesi.

Conservation Status: Least Concern (LC) based on the latest assessment carried out by the IUCN Red List in 2014 (Clarke, 2018g). Most of the population of *Nepenthes tentaculata* occur in the TPA areas.

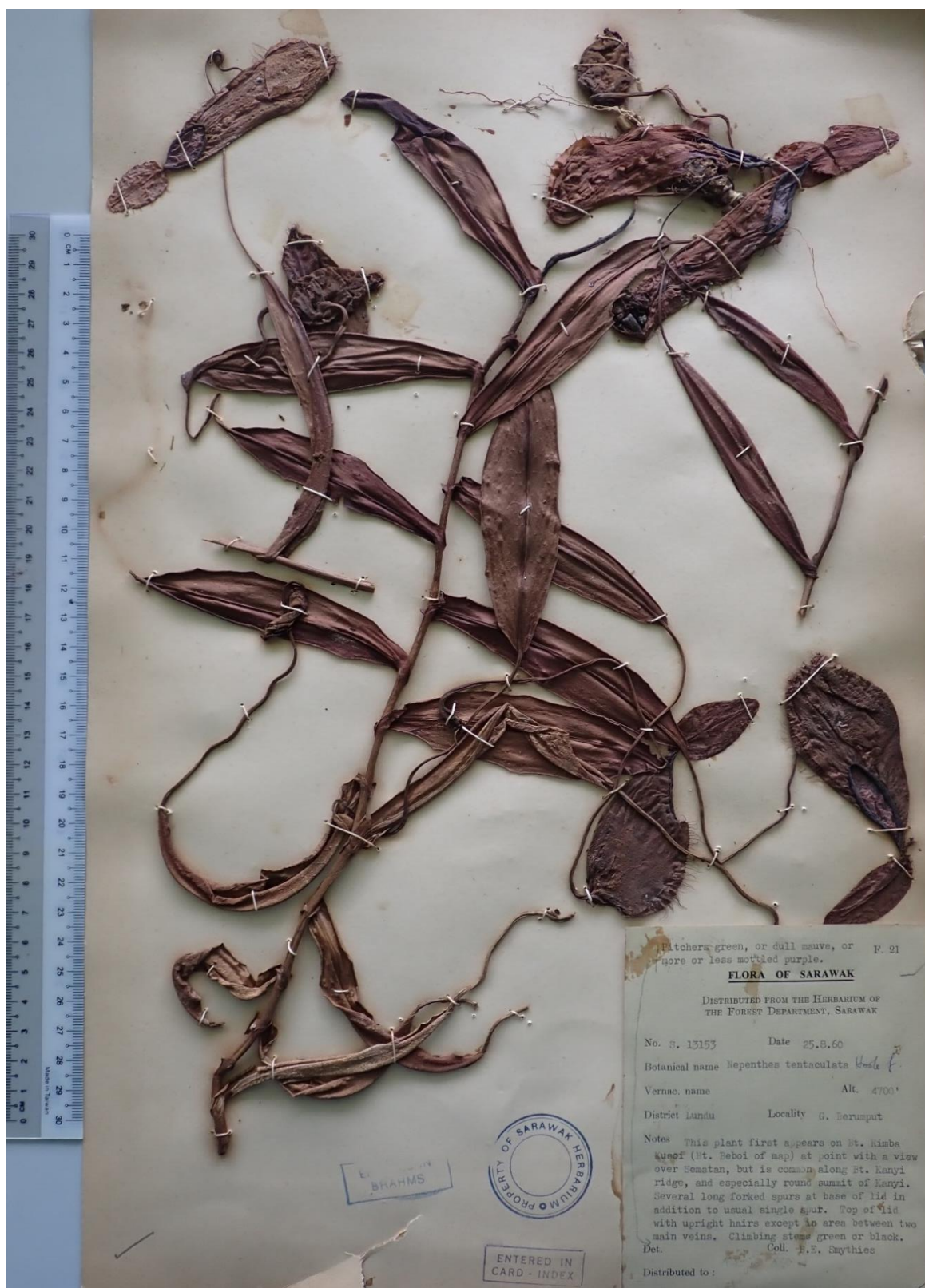


Figure 4.38: Herbarium specimen of *Nepenthes tentaculata* Hook. f. Sarawak, Kuching Division, Lundu, Gunung Berumput, 25 August 1960, Smythies, B. E., S13153 (SAR)

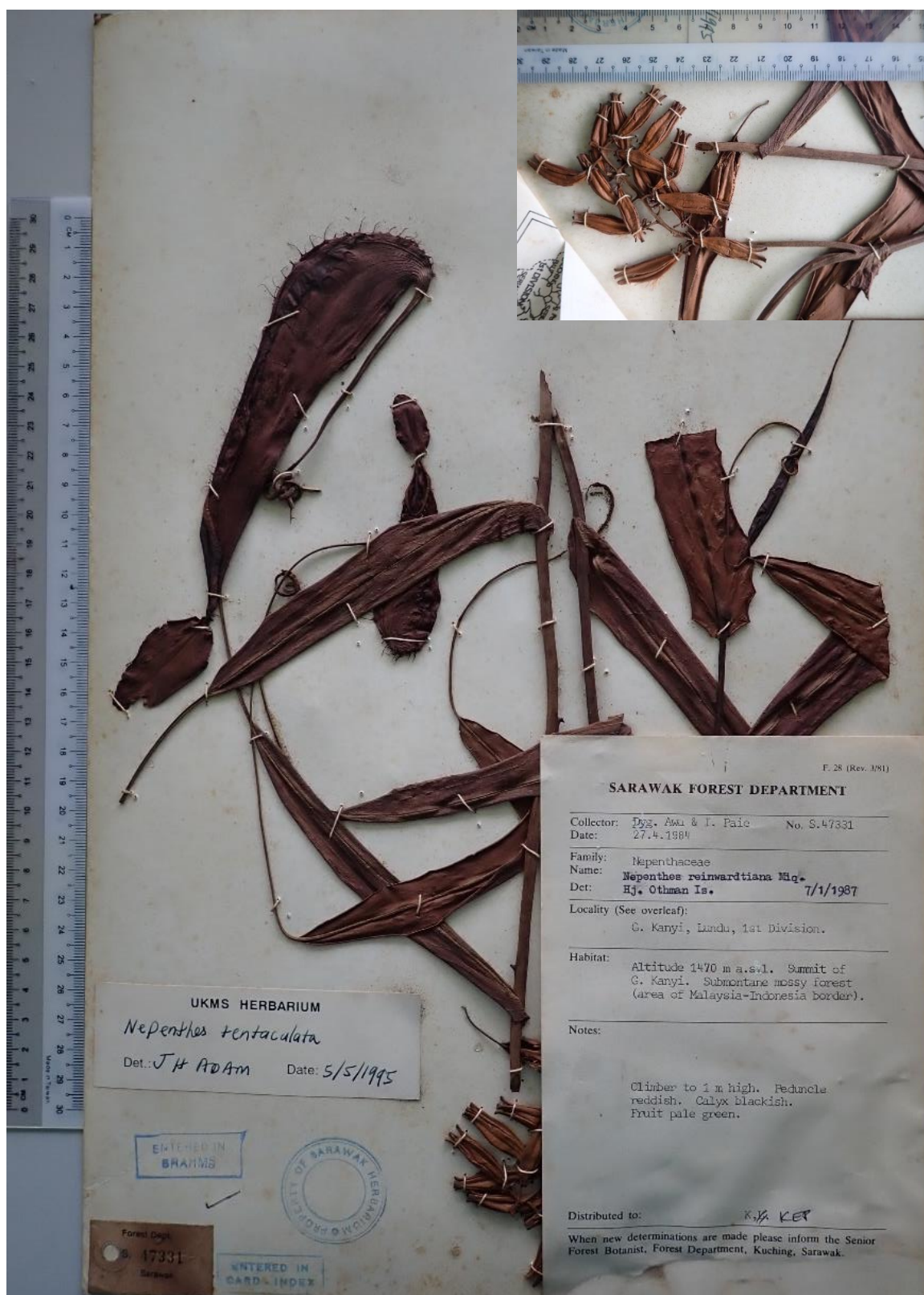


Figure 4.39: Herbarium specimen of *Nepenthes tentaculata* Hook. f. Sarawak. Borneo, Malaysia, Sarawak, Kuching Division, Lundu, Gunung Kanyi, 27 April 1984, Dyg. Awi & Paie, T., S47331 (SAR)

14. *Nepenthes veitchii* Hook. f.

Nepenthes veitchii Hook.f., Trans. Linn. Soc. 22 (1859) 421; Danser, Bull. Jard. Bot. Buitenzorg III, 9 (1928) 391; Phillipps & A. L. Lamb, Pitcher Plants of Borneo (1996) 144, f. 77 & 78; Jebb & Cheek, Blumea 42 (1997) 89; Clarke, *Nepenthes* of Borneo (1997) 131, f. 91 & 92.

Type specimen: Lobb s.n. (lecto K), Borneo.

Synonym: *Nepenthes lanata* Hort. ex Linden, *N. veitchii* var. *striata* Veitch, *N. villosa* auct. non Hook. f.: Hook., *N. sanguinea* auct. non Lindl.: Mast.

Description: **Stem** woody, terete-flexuose, 5-8 mm diam., densely covered with hairs, up to 2 mm long, rarely 2-ridged, 5-8 mm diam., internodes 2-4 cm. **Leaves** coriaceous, petiolate, long obovate-ob lanceolate, apex retuse-slightly truncate, base cuneate-obtuse, 5.2-30 × 2-8.2 cm wide; petiole 1.5-19.5 cm, winged, canaliculate, sheathing to the stem, clasping 2/3 of the stem circumferences, leaf deccurency 1-2 cm. Longitudinal nerves 2 - 4 on each side of the midrib. Pennate nerves inconspicuous, nearly parallel to the main vein, slightly angled at 45°. **Lower pitchers** broadly cylindrical, narrow at the base, broadest at the middle part of the pitcher, 12-27 cm × 3-8 cm, with two fringed wings, 2-6 mm wide, 1.1-3 cm apart, fringe elements c. 5-8 mm long, 3-8 mm apart; mouth ovate, 4-6 × 1-4 cm, horizontal in front, abruptly concave behind, rising into a long, broad, stout column above the front of the mouth; peristome flattened, 0.5 cm wide at the front, 1 - 5.5 cm wide near the lid, wavy at the outer edge, inner edge with teeth c. 1-2 mm long; lid narrowly ovate-elliptic, 3.5-6 × 3-4 cm, apex rounded, base rounded, glands densely presence on the abaxial of the lid, 1-2 mm diam. Spur not observed. **Male inflorescence** 25-30 cm long, peduncle 12.8-13 cm long, pedicels 2-branched onto the peduncle, 1.0 cm long, androphore 0.2-0.3 cm long, 0.1

cm diam. **Female inflorescences** 21-27 cm long, grow near the terminal of the plant, peduncle 14-15.8 cm long, pedicles 2-branched, infructescences 2.4–4 cm long, 2–3 mm wide, seeds filiform, 1.5–2.2 cm long. **Indumentum** densely covered on the stem, juvenile pitchers. **Colour** not seen (Herbarium specimen).

Specimens Examined: Sarawak, Kuching Division, Mt. Santubong, Dec 1906, *Hewitt*, *Hewitt series 458* (SAR); 23 Aug 1957, *J.A.R Anderson* and *T.C.W*, *S8421* (SAR) (Figure 4.41); 30 May 1962, *B.L Burt* and *P.J.B. Woods*, *B1981* (SAR); 24 March 1963, *B.E. Smythies*, *S15327* (SAR); 21 Dec 1975, *P.F. Stevens* et al., *P.F Stevens 317* (SAR) (Figure 4.40); Sri Aman Division, Lingga, Gunung Lesong, mossy forest, 4 Dec 1981, *Bernard Lee*, *S44290* (SAR); Simanggang, summit of Gunung Lesong, submontane kerangas forest, 18 Apr 1960, *J.A.R Anderson*, *S12877* (SAR); summit of Klingkang Range, swampy flat kerangas forest, 28 June 2000, *L.C.J. Julaihi* et al., *S83456* (SAR).

Distribution: Endemic to Borneo. Sarawak, Brunei, and Kalimantan (rare).

Habitat and Ecology: Occur in lowland to highland areas, up to 1800 m a.s.l. This species grows in the lowland dipterocarp forest, usually near the rivers, and mossy forest on the mountain ridges.

Conservation Status: Least Concern (LC) according to the latest assessment by IUCN Red List in 2014. Most of this Bornean endemic population are located in in the TPA areas.



Figure 4.40: Herbarium specimen of *Nepenthes veitchii* Hook. f. Sarawak, Kuching division, Santubong, 23 August 1957, T.C.W and Anderson, J. A. R. S8421 (SAR)



Figure 4.41: Herbarium specimen of *Nepenthes veitchii* Hook. f. Sarawak, Kuching Division, Santubong, 21 December 1975, Stevens, P. F. P.F Stevens 317 (SAR)

15. *Nepenthes x bauensis* Chien C. Lee

Nepenthes x bauensis Chien C. Lee, *Nepenthes*, Sarawak Museum Journal 59 (2004) 171-177; Phillipps & A.L. Lamb, Pitcher Plants of Borneo (1996) 138, f. 74

Type specimen: Gn. Umbut, 26 Mar 02. Limestone, opened area, foothill. Meekiong, K., SBC 2701.

Description: Terrestrial climber or scrambler to 2 m high. Climbing stems triangular torounded, 6 mm diam., internodes 3–4.5 cm. **Leaves** of the climbing stems coriaceous, sessile, lanceolate to slightly oblong-lanceolate 16–18 × 2.5–3 cm, apex acute, occasionally sub-peltate, base narrowing and decurrent into stem wings extending $\frac{1}{2}$ – $\frac{3}{4}$ length of internode. **Upper pitchers** subcylindrical, slightly swollen in the lower half and slightly expanded below the mouth, 14–14.5 × 3–3.7 cm, with two fringed wings extending down the entire length of the pitcher; mouth ovate; peristome rounded to slightly flattened in cross section, 2–6 mm wide, ribs c. 0.4 mm apart; lid as large as or larger than mouth, broadly elliptic to suborbicular, 4.5–5 × 3–3.5 cm; spur simple, to 4 mm long. **Male inflorescence** length unknown; peduncle 6 cm long; partial-peduncles 2-flowered, bracts absent, to 1.6 cm below the branch, with each branch to 1 cm long; tepals ovate, to 4 mm long; androphore c. 1 mm long. **Female inflorescence** unknown. Indumentum absent from all parts except for outer surface of pitcher which consists of scattered short simple brown hairs.

Specimens Examined: Sarawak, Kuching division, Bau, Gunung Umbut, limestone, opened area, foothill, 26 March 2002, *Meekiong*, K., SBC2701 (SAR) (Figure 4.42).

Etymology: The epithet name was given after its origin place, Bau, Sarawak.

Habitat and Ecology: Grow at the opened area and foothill of limestone area.

Distribution: So far, this hybrid was recorded from a single location in the limestone area in Bidi at Bau, Kuching division, Sarawak.



Figure 4.42: Herbarium Type specimen of *Nepenthes x bauensis* Chien C. Lee. Sarawak, Kuching Division, Bau, Gunung Umbut, 26 March 2002, Meekiong, K., SBC 2701 (SAR)

16. *Nepenthes x hookeriana* Hort. Veitch ex Mast.

Nepenthes x hookeriana Lindl., Gard. Chron. (1848) 87, nomen; Mast., Gard. Chron. (1881) 812, f. 157; G. Nicholson, 111. Diet. Gard. 4 (1886) 436; Gard. Chron. (1892) 561, ic. 557; Boerl., Handl. 3, 1 (1900) 54; Burb., Flora & Sylva II, 12(1904) III; Macfarl. in Engl., Pflanzenr. 4, 3 (1908) 34; Danser, Bull. Jard. Bot. Buitenzorg III, 9 (1928) 309, f. 9; Shivas, Pitcher Plants of Peninsula Malaysia & Singapore (1984) 33; Phillipps & A.L. Lamb, Pitcher Plants of Borneo (1996) 94, f. 7; Jebb & Cheek, Blumea 42 (1997) 50; Clarke, *Nepenthes of Borneo* (1997) 153, f. 106.

Type specimen: Low (not located), Borneo, Sarawak.

Synonym: *Nepenthes loddigesii* W. Baxter, *Nepenthes hookeri* Alphand ex Hook. f., *N. rafflesiana* var. *hookeriana* (Lindl.) Beck, *N. rafflesiana* auct. non Jack, *N. hookeriana* auct. non Lindl.

Descriptions: Rosette, grow up to 25 cm. **Stem** woody cylindrical, c. 11.2 mm diam., greenish brown, covered with numerous brown indumentum. Internodes 4 mm. **Leaves** thickly coriaceous, 10–18 × 4.8–6.2 cm, blade lanceolate–elliptical, apex acuminate, sometimes slightly acute, base cuneate, petiolate, winged (folding inward), 4 mm broad at each side of petiole, decurrent into stem up to 1.3 cm, clasping the stem $\frac{3}{4}$ of its circumference. Margin of leaves entire. Longitudinal veins 3 at each side of the midrib near the margin, inconspicuous, pennate nerves numerous, inconspicuous, ascending 45° from the midrib, then descendent to the margin. **Lower pitcher** globose or urceolate, slightly ovoid, 6–8.5 cm long, 3–4.3 cm wide, fringed wings, 2, up to 1.2 cm wide, fringe elements 3–7 mm, c. 1 mm apart; mouth ovate, peristome slightly flattened inward, ribs c. 1 mm apart, outer edge entire, inner edge toothed, up to 2 mm long. Lid narrowly ovate, slightly oblong,

apex of lid, slightly notched, nectar glands scattered all over the abax of lid. Spur simple, c. 5 mm long. **Indumentum** white present on the abax, and adax of leaves, body of pitchers, stem, tendril. **Colour** of leaves whitish green on the adaxial, green fused with brownish–red colour on the abaxial with red spots.

Specimen Examined: Sarawak, Kuching Division, Matang-Sampadi Roadside, kerangas disturbed area, 23 March 2022, *Nabilah Huda* et al., *NH0049* (Herbarium of Universiti Malaysia Sarawak).

Etymology: This plant was named after Sir Joseph Dalton Hooker, a British botanist who once served as a director of Royal Botanic Garden, Kew.

Habitat and Ecology: Occur in a mixed population at the lowland areas with their parental plants, *N. ampullaria* and *N. rafflesiana*.

Distribution: Borneo, Peninsular Malaysia, Singapore, and Sumatra.

Notes: This taxon was firstly described as a variety of *Nepenthes rafflesiana*, but later was redescribed as a natural hybrid between *N. ampullaria* and *N. rafflesiana*

17. *Nepenthes x kuchingensis* Sh. Kurata

Nepenthes x kuchingensis Sh. Kurata, J. Insectiv. Pl. Soc. 33: 36 (1982); Phillipps & A.L. Lamb, Pitcher Plants of Borneo (1996) 138, f. 74.

Type specimen: The type material is not located.

Synonym: *Nepenthes x cutinensis* Hort. ex Lauffenburger (1995) *nom. Nud.*

Descriptions: Terrestrial rosettes up to 15 cm tall. **Stem** woody, terete, c. 3.42 mm diam., internodes c. 1 cm. **Leaves** petiolate, chartaceous, blade oblanceolate, apex 7–22 × 1.6–4.5 cm, apex acute, slightly acuminate, base attenuate, clasping $\frac{1}{2}$ - $\frac{3}{4}$ of its circumference. Margin entire. Longitudinal veins 3–4 at each side midrib, pennate veins obscure. Tendril 4.5–8 cm. **Lower pitchers** globose at the base and abruptly narrow at the middle and forming cylindrical at the upper, 3.5–7 × 1.5–2.5 cm, wings c. up to 4 × 0.3 cm, fringed wings c. 3 mm, width between two wings c. 2 mm; mouth ±elliptical, 15.34 × 10.83 cm; peristome cylindrical, up to 1.5 mm wide, ribs very fine, outer edge entire inner edge lacking teeth; lid narrowly oblanceolate, 2 x 1 cm, spur simple, c. 5 mm. **Indumentum** presence on the leaves, tendril, surface of the pitcher. **Colour** of leaves light green to green, slightly spotted with red, midrib red on the adaxial, pitcher light green suffused with pinkish red.

Specimen Examined: Sarawak, Samarahan Division, Kota Samarahan, Universiti Malaysia Sarawak, UNIMAS Arboretum, peatswamp-kerangas forest, Dec 2020, *Nabilah Huda* et al., *NH0037* (Herbarium of Universiti Malaysia Sarawak).

Etymology: This natural hybrid was named after a capital city, Kuching that is located in Sarawak state, Malaysia.

Habitat and Ecology: Normally grows in peat swamp forest, and disturbed habitats such as roadside embankments and disturbed kerangas forest with its parent plants, *Nepenthes ampullaria* and *N. mirabilis*.

Distribution: Commonly found in Borneo.

18. *Nepenthes x trichocarpa* Miq.

Nepenthes x trichocarpa Miq., Fl. Ned. Ind. 1, 1 (1858) 1072; J. Bot. Neerl. 1, 3 (1862) 275, t. 1; Danser, Bull. Jard. Bot. Buitenzorg III, 9 (1928) 389; Tamin & M. Hotta in M. Hotta, Diversity and Dynamics of Plant Life in Sumatra (1986) 108; Phillipps & A.L. Lamb, Pitcher Plants of Borneo (1996) 140, f. 75; Jebb & Cheek, Blumea 42 (1997) 87; Clarke, *Nepenthes* of Borneo (1997) 150, f. 104.

Type specimens: Teijsmann 532 p.p. (BO, L n.v., U n.v.), Sumatra, Sibolga, 0 m, Feb. 1856.

Synonym: *Nepenthes trichocarpa* var. *erythrosticta* Miq.

Descriptions: Terrestrial climber up to 50 cm. **Stems** woody, cylindrical, slightly triangular, 3.2–3.7 mm, brown sometimes greenish–brown, internodes 2–4.5 cm (internodes increasing from the base). **Leaves** sessile, coriaceous, 5.2–16 × 1.2–3.2 cm width, narrowly lanceolate, slightly oblanceolate, apex acute–acuminate, base narrowing, decurrent into stem up to 2.5 cm, clasping the stem $\frac{1}{2}$, or sometimes $\frac{3}{4}$ of its circumference. Margin entire. Longitudinal veins 3 on each sides of the midrib near to the margins. Pennate nerves obscure, ascending at 45° from the midrib. **Upper pitchers** globose–ellipsoid at the basal half, gradually becoming slightly constricted towards the subcylindrical at the upper half, 4–7 cm long, 1.4–3.2 cm in the lower half, 1.2–2.4 cm in the upper half. Fringe wings c. 3 mm wide, fringe element c. 2.5 mm, c. 1 mm apart; mouth ±ovate, peristome cylindrical in section, c. 1 mm wide, ribs inconspicuous, outer edge entire, inner edge minutely toothed; Lid ovate–orbicular, 1.2–2 × 1–1.4 cm, nectar glands minutely sparse on the lower surface of lid, circular shape; spur simple, sometimes 2-branched, 4–5.5 mm. **Indumentum** present, stellate hairs brown present on the abaxial leaves, pitcher’s body. **Colour** green on the adaxial of leaves, sometimes blotches with purplish–red colour, light green on the abaxial

leaves, freckles with pinkish–red spot, juvenile leaves are greenish–brown on the abaxial and adaxial, pitchers light green freckles with purplish–brown, lid light green on the abaxial, with purplish–brown on the margin, adaxial lid light green freckles with purplish–brown, peristome entirely light green.

Specimen Examined: Sarawak, Kuching Division, Matang-Sampadi Roadside, disturbed kerangas area, 23 March 2022, *Nabilah Huda* et al., *NH0048* (Herbarium of Universiti Malaysia Sarawak).

Etymology: The epithet name of *Nepenthes* x *trichocarpa* is derived from two Greek words; *trikho* (hair, thread), and *carpus* (fruit).

Distribution: Borneo, Peninsular Malaysia, and Sumatra.

Habitat and Ecology: Occurs in the lowland area up to 800 m a.s.l and usually in company with its parent plants.

Notes: This taxon, vernacularly known as the dainty pitcher plant was known later as a species (*N. trichocarpa*) by Miquel in year 1858 based on the specimens collected by Teijsmann in Sumatra Utara. But then, it was redescribed as a natural hybrid between *N. ampullaria* and *N. gracilis* as suggested by Holttum in year 1940 (Cheek and Jebb, 2001).

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

The current research has fulfilled the research objectives mentioned. A total of 18 *Nepenthes* taxa were successfully recorded from western Sarawak which involves 13 species, one variety, and four natural hybrids. Fourteen taxa were described based on the fresh living specimens collected from random areas in western Sarawak, while the remaining four taxa were examined based on the herbarium specimens deposited in Sarawak Herbarium (SAR).

The majority of *Nepenthes* taxa were found distributed in a wide range of habitats mostly in Samarahan and Kuching followed by Serian and Sri Aman with only a few taxa that can be found restricted to specific areas such as limestone areas. All of them grow in acidic and wet or dry soil either in shady or highly exposed areas. *Nepenthes ampullaria*, *N. gracilis*, *N. mirabilis*, and *N. rafflesiana* were the commonest taxa that can be found in many areas. Five endemic taxa of Sarawak were included in the study as well namely *Nepenthes hispida*, *N. mirabilis*, *N. mirabilis* var. *echinostoma*, *N. nazreeana* sp. nov. ined., *N. northiana*, and *N. x bauensis*. Another three recorded *Nepenthes* taxa in this study; *N. bicalcarata*, *N. hirsuta*, and *N. veitchii* were declared as Bornean endemic.

This examination of specimens also has provided ample information, particularly on the morphological characteristics together with the aid of past literature mainly by Clarke (1997), Cheek and Jebb (2001), Phillips et al. (2008), and Steiner (2010). The *Nepenthes* studied showed two types of variations which are interspecific and intraspecific variation. Overall, most of the *Nepenthes* are identified based on their pitcher characteristics which are

mainly noticeable through their pitcher shape, sizes and colour, peristome, and lid. However, other characteristics such as the type of stem, bases and leaf margin were identified to be a good spot character that could delineate the taxa such as saddle-shaped wings on the leaf bases in *N. northiana*.

The anatomical study; epidermal layers and midrib cross-section show distinct characteristics between the *Nepenthes* taxa studied. Thirteen taxa were included using fresh living specimens. The majority of the leaves developed hypostomatic leaves with only one taxon forming amphistomatic leaves. The anomocytic stomatal complex type was distributed abundantly on the abaxial surfaces of leaves with different sizes and densities among the polygonal epidermal cells compared to the adaxial leaves. Four informal groups were formed to classify the *Nepenthes* taxa based on their stomatal density; **Group 1** (Stomatal density $\leq 100 \text{ mm}^{-2}$), **Group 2** (Stomatal Density $101 \leq 200 \text{ mm}^{-2}$), **Group 3** (Stomatal Density $201 \leq 300 \text{ mm}^{-2}$), and **Group 4** (Stomatal Density ≥ 301). The types of stomata formation in *Nepenthes* studied were identified as well via Field Emission Scanning Electron Microscopy (FESEM) which are sunken stomata, semi-raised stomata, and raised stomata. The patterns of the anticlinal wall of *Nepenthes* leaves at the adaxial and abaxial surfaces were observed which formed in two types which are straight and sinuous.

The midrib cross-section revealed different types of midrib outer shapes which are categorised as Type 1, Type 2, Type 3, and Type 4. The 13 *Nepenthes* studied produced a complex structure of vascular structure, with closed ring systems that were observed in different shapes. Their consistent collateral and closed vascular bundles are arranged as main vascular bundles, medullary vascular bundles, and additional vascular bundles and are present in different numbers among the 13 *Nepenthes* taxa studied. These characteristics have a taxonomic value that could be used to differentiate the taxa in the genus *Nepenthes*.

The micromorphological observation through FESEM revealed a variety of types of glandular and non-glandular trichomes distributed mostly on the adaxial and abaxial of leaves in *Nepenthes*. The identified trichomes are peltate glandular trichome, capitate glandular trichome, short or long stellate rotate trichome, scale trichome, and simple unicellular with smooth or scale on surface and/or branched at the base. This study also focused on the observations of the lunate cells and digestive glands of the pitchers. These features occur on the inner surface of the pitcher that crucial to help in trapping and digesting prey for nutrient absorptions in the plant.

Lunate cells were present in a majority of the *Nepenthes* taxa studied except *N. ampullaria*, *N. x hookeriana*, and *N. x kuchingensis*. The lunate cells, a modified stomatal complex that formed below the peristome are covered with an abundance of wax crystal which makes these zones waxy and slippery. The lunate cells are developed in different lengths and densities among the 13 *Nepenthes*. The digestive glands were seen in circular to elliptical shapes and present in all the 13 *Nepenthes* studied. They are conspicuously different in sizes and densities among the *Nepenthes* studied. These features can be a good diagnostic character to distinguish the taxa in this genus.

The palynological study of *Nepenthes* taxa in western Sarawak shows homogenous characteristics which only differ in terms of their sizes. The pollen grains were formed in tetrahedral tetrad with echinate-microechinate on its surface ornamentation. These characteristics are not useful to help in delimiting the taxa in the genus *Nepenthes*.

Briefly, the identification of the taxa in genus *Nepenthes* particularly in western Sarawak can be made basically on its morphological characteristics. However, due to its taxonomic challenges, they can be supported by other aspects of the study such as anatomical, and micromorphological characteristics of the taxa in the genus. These aspects

have proven to provide important taxonomic value to delineate the *Nepenthes* taxa. Other studies such as the palynological characteristics of *Nepenthes*, however, are not taxonomically useful as the characteristics are homogenous among the taxa studied. The ecology and distribution of the *Nepenthes* taxa studied also provided information to understand the endemism of the taxa, common taxa and others.

5.2 Recommendations

Genus *Nepenthes* has received massive attention from botanist worldwide because of their unique morphological characteristics and great interaction ecologically. Despite many studies that have been conducted to aid in classifying the members of the genus, there is still a lack of information on other aspects. Several recommendations have been made to fill in the knowledge gaps that can be used in distinguishing the taxa in *Nepenthes* taxa.

- The systematic revision of *Nepenthes* in Sarawak must be kept updated as the number of *Nepenthes* species is rapidly increase which sometimes can cause by taxonomic inflation in the genus.
- A further thorough study of the anatomical and micromorphological aspects of the *Nepenthes* in Sarawak should be conducted intensively to identify useful characteristics that can be another alternative to distinguish the taxa well.
- The pollen characteristics of *Nepenthes* taxa that are newly discovered should be examined as it may become a potential aspect in the taxonomical identification of this genus in future.

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APPENDICES

Appendix A: List of distribution data of 18 *Nepenthes* taxa in western Sarawak

Species	Division	Localities	Latitude	Longitude	Voucher Specimen No.
<i>N. ampullaria</i>	Kuching	Mt. Santubong NP	1°44'43"N	110°19'6"E	NH0008; NH009; NH0010
		Mt. Serapi NP, Summit trail	1°35'20"N	110°11'25"E	NH0038
		Gunung Pueh FR	1°48'3"N	109°40'58"E	*N/A
		Aquilaria Plantation, Bau	1°28'32"N	110°10'50"E	NH0029
		Banjaran Undan SF	1°27'43"N	110°1'52"	NH 0034
		Bako NP	1°43'10"N	110° 27'11"E	*N/A
		Matang Wildlife Centre	1°36'34"	110°9'36"	*N/A
		Sabal FR	1°4' 8.58"N	110°54'42"N	*N/A
	Samarahan	UNIMAS Arboretum	1°27'53"N	110°26'48"E	NH 0005
		Along the main roadside of Samarahan - Kuching	*N/A	*N/A	*N/A
<i>N. bicalcarata</i>	Sri Aman	Betong, Saribas.	*N/A	*N/A	S8533
	Kuching	Loba Kara	1°24'1.74"	110°7'0"	S2820A
<i>N. albomarginata</i>	Kuching	Bako NP	1°43'21.65"	110°26'54.46"	NH0017; NH0018
		Gunung Pueh Forest Reserve	1°48'3"N	109°40'58"E	NH0038
		Mt. Serapi, Kubah NP	1°35'20"N	110°11'25"E	NH0039
<i>N. gracilis</i>	Kuching	Gunung Poing	1°22'0"N	110°4'0"E	NH0001

Appendix A continued

		Bako NP	1°43'18"N	110°27'06"E	NH 0032
		Banjaran Undan SF	1°27'43"N	110°1'52"	NH0028
		Dered Krian	1°22'50"	110°9'47"E	*N/A
		Matang-Lundu Roadside	110°7'5"N	1°38'41"E	NH0015, NH0021
		Aquilaria Plantation	1°28'32"N	110°10'50"E	NH0027
		UNIMAS Arboretum	1°27'53"N	110°26'48"E	NH 0005
		Along the roadside of Samarahan-Kuching	*N/A	*N/A	*N/A
	Samarahan	UNIMAS Arboretum	1°27'53"N	110°26'48"E	NH 0005
		Along the roadside of Samarahan-Kuching	*N/A	*N/A	*N/A
<i>N. hirsuta</i>	Kuching	Banjaran Undan SF	1°27'43"N	110°1'52"	NH0030, NH0031, NH0036, NH0039, NH0040, NH0041, NH0042, NH0046
		Kubah NP	1°35'20"N	110°11'25"E	*N/A
<i>N. hispida</i>	Kuching	Bako NP	1°43'09"N	110° 27'12"E	NH0047
		Banjaran Undan SF	1°27'43"N	110°1'52"E	NH0048
<i>N. mirabilis</i>	Samarahan	UNIMAS	1°27'53"N	110°26'48"E	NH0001, NH002, NH0006
	Kuching	Banjaran Undan SF	1°29'19"N	110°04'07"	NH 0028
		Dered Krian	1°22'50"N	110°9'47"E	*N/A
		Gunung Pueh FR	1°48'3"N	109°40'58"E	*N/A
		Matang-Lundu Roadside	110°7'5"N	1°38'41"E	NH0014; NH0022

Appendix A continued

		Along the Roadside of Samarahan	*N/A	*N/A	*N/A
<i>N. mirabilis</i> var. <i>echinostoma</i>	Kuching	Gunung Pueh FR	1°48'3"N	109°40'58"E	NH0038
<i>N. nazreeana</i> sp. nov. ined.	Kuching	Matang-Lundu Roadside	1°38'41"E	110°7'5"N	NH0019, NH0012
<i>N. northiana</i>	Kuching	Fairy Cave NR	1°22'50"N	110°7'25"E	*N/A
		Siburan, Bau	1°22'11.54"N	110°2'47"E	S15476, S9094
		Gunung Aup, Bau	1°22'4.91"N	110°3'1.21"E	SBC242
		Tai Ton Limestone Hill, Bau	1°24'10"N	110°8 1.23E	S51217, P.F Stevens 203
		Bukit Numpang, Tai Ton, Bau	*N/A	*N/A	S22862
		Gunung Tabai, Tai Ton, Bidi road, Krokong, Bau	1°22'60"N	110°7'60"E	S82103, B1914
		Bukit Bidi, Bau	1°24'8.65"N	110°5'58.76"E	S50394
		Kampung Bidi, Bau	1°25'4"N	110°9'41"E	S70248, S70247
		Gunung Ropih, Bau	1°22'60"N	110°7'60"E	SBC2412, SBC2413
		Bukit Kapor, Bau	1°22'59"N	110°7'0"E	S 15244
		Gunung Umbut, Bau	1°24'1.74"N	110°7'0"E	SBC2078
	Serian	Mile 15 th , Tebedu	1°0'59"N	110°21'28"E	S49230
<i>N. rafflesiana</i>	Kuching	Bako NP	1°43'19"N	110°27'04"	NH0012
		Banjaran Undan	1°27'43"N	110°1'52"	NH0040
		Matang-Lundu Roadside	1°38'41"E	110°7'5"N	NH0020
		Sabal FR	1°4'8.58"N	110°54'42"N	*N/A

Appendix A continued

		Mount Santubong NP	1°44'16"N	110°19'4"E	NH0016
		Matang Wildlife Centre	1°36'34"	110°9'36"	*N/A
<i>N. reindwartiana</i>	Kuching	Bako NP.	1°42'58"N	110°26'31"E	NH0051
<i>N. tentaculata</i>	Kuching	Mt. Serapi, Kubah NP	1°35'20"N	110°11'25"E	S13142
		Mount Santubong NP	1°44'16"N	110°19'4"E	S15326
		Bungo Range NP, Pedawan	1°15'32"N	110°8'7"E	S7632, S9504
		Gunong Berumput, Poi Range,	1°42'49"N	109°40'57"E	B2792, S13153
		Gunung Kanyi, Lundu	1°42'52"N	109°40'24"E	S47331
	Serian	Gunung Penrissen, Siburan	1°7'7.24"N	110°12'59"E	S16393
	Sri Aman	Bukit Tiang Laju	1°4'8"N	111°39'0"E	*SAR
<i>N. veitchii</i>	Kuching	Mount Santubong	1°44'2.93"N	110°20'0.31"	S8421, S1906, S1981, S15327, S317
	Sri Aman	Summit of Gunung Lesong	1°15'39"N	111°9'9.27"E	S12877
		Summit of Klingkang Range	1°1'734"N	110°57'440"E	S83456
<i>N. veitchii</i>	Kuching	Mount Santubong	1°44'2.93"N	110°20'0.31"	S8421, S1906, S1981, S15327, S317
	Sri Aman	Summit of Gunung Lesong	1°15'39"N	111°9'9.27"E	S12877
		Summit of Klingkang Range	1°1'734"N	110°57'440"E	S83456
<i>N. x bauensis</i>	Kuching	Gunung Umbut, Bau	1°24'1.74"N	110°7'0"E	SBC2701
<i>N. x hookeriana</i>	Kuching	Matang –Lundu Roadside	1°38'41"N	110°7'15"E	NH 0049
<i>N. x kuchingensis</i>	Samarahan	UNIMAS Arboretum	1°27'53"N	110°26'48"E	NH 0037
<i>N. x trichocarpa</i>	Kuching	Matang-Lundu Roadside	1°38'41"N	110°7'5"E	NH 0048

****Notes:** Mount (Mt), Forest Reserve (FR), National Park (NP), Nature Reserve (NR), Stateland Forest (SF), Universiti Malaysia Sarawak (UNIMAS), No Information available (*N/A), SAR herbarium specimen (*SAR)

Appendix B: Morphology comparison of pitchers in lower, and upper pitcher plant of *Nepenthes* studied

<i>Nepenthes</i> Species	Shape of Pitcher		Average Size of Pitcher, (Length × Width (cm))		Colour
	Lower pitcher	Upper pitcher	LP	UP	
<i>N. albomarginata</i>	Ellipsoid at the base, tapering gradually into cylindrical upper half	Cylindrical to infundibulate	4.5-12.5 × 0.5-2 cm	8.5-13 × 2-3 cm	Light green or dark purple blotches with
<i>N. ampullaria</i>	Urceolate	N/A	2.5-9.5 × 1.5-7.5 cm	N/A	Light green or light green freckled with red to purple colour.
<i>N. gracilis</i>	Base ellipsoid, gradually narrower at the middle towards the subcylindrical at the upper half.	Subcylindrical, constricted at the middle, and slightly ellipsoid at the base.	5.7-7.2 × 1.2-1.8 cm	5.5-7.5 × 1.2-2.0 cm	Green, red, or green mottled with red to dark purple.
<i>N. hirsuta</i>	Ovoid or ellipsoid, tapering into a shortly cylindrical at the upper part below the peristome.	Ovoid to cylindrical. Slightly similar as the lower plant.	6-18 × 3-6.5 cm	4-13 × 2-3.5 cm	Green, red or green splashed or freckled with red. (LP) Always green (UP)

Appendix B continued

<i>N. hispida</i>		N/A	Cylindrical with slightly ovoid at the base.	N/A	3.5–10 × 2.5–3	Green with flecked red on the inner side of the pitcher at the upper half.
<i>N. mirabilis</i>	Ovoid in the basal half, and cylindrical in the upper half.		Slightly infundibuliform at the basal half and cylindrical at the upper half with distinct ‘hipped’ point half from the base, or subcylindrical and slightly flattened at the vertical side.	8.5–14 cm × 3.3 – 4.5 cm	10.2–13.5 × 1.5–5.5 cm	Light green suffused with pinkish – red, wholly light green, or light green and strongly blotches with purplish-red.
<i>N. mirabilis</i> var. <i>echinostoma</i>		N/A	cylindrical at the base up to the upper part with slightly ventricose at the middle,	N/A	14.5–18.5 × 4–6	Light green suffused with pinkish –red on the upper half
<i>N. nazreena</i> sp. nov. ined	Cylindrical at the upper half, ovoid at the base.		Cylindrical at the base up to the upper part with slightly ventricose at the middle	14–19 × 5–6 cm	17.2 – 18.7 cm x 3.5 – 4.0 cm	Light green splashed with dark red.
<i>N. northiana</i>	Broadly ellipsoid, recumbent.		Cylindrical to infundibulate	3.5–29.5 × 2.5–6.5 cm	26.5 × 5.4 cm	N/A

Appendix B continued

<i>N. rafflesiana</i>	Ovoid or broadly ovoid to subglobose at the base and slightly narrower to the upper.	Infundibuliform or narrowly infundibuliform, broader at the upper half near the mouth	12-25 × 4-7 cm	13-18.5 × 3-6 cm	Green or pale green blotches with red to dark purple freckles
<i>N. reinwardtiana</i>	N/A	Basal half ellipsoid or slightly ventricose, gradually narrower at the middle towards the subcylindrical at the upper half.	N/A	9.0-14 × 2-3.5 (at the base)	Light green to green, sometimes suffused with brownish-red colour.
<i>N. tentaculata</i>	Broadly subcylindrical, slightly ovoid at the base.	Subcylindrical to broadly subcylindrical or ovoid at the base,	4.0-6.5 × 1.0-2.4	5.0-15.6 × 1.0-3.0	N/A
<i>N. veitchii</i>	Broadly cylindrical, narrow at the base, broadest at the middle part of the pitcher	Similar as lower but smaller.	12-27 × 3-8 cm	N/A	N/A
<i>N. x bauensis</i>	Not observed	Subcylindrical with a slightly swollen at the base, and slightly expanded at the upper below the mouth.	N/A	11.65-15.60 × 3.0-3.2	N/A
<i>*N. x hookeriana</i>	Globose or urceolate, slightly ovoid	*Not observed	6.0-8.5 × 3.0-4.3	N/A	Light green blotches with purplish red.

Appendix B continued

<i>N. x kuchingensis</i>	Globose at the base and abruptly cylindrical at the upper part of pitcher.	*Not observed	3.5–7 × 1.5–2.5	N/A	Green suffused with slightly pinkish red.
<i>N. x trichocarpa</i>	*Not observed	Globose – ellipsoid at the basal half, gradually becoming slightly constricted towards the subcylindrical at the upper half.	4.0 – 7.0 × 1.4 – 3.2	N/A	Light green freckles with purplish brown.

*N/A = Not observed, the samples are not found in the field or not available in SAR herbarium.

Appendix C: Publications

1. **Nabilah Huda, M. H.**, Meekiong, K. & Elias, H. (2022). Leaf Anatomical Characteristics of *Nepenthes* in western Sarawak, Borneo. *Malaysian Applied Biology*, 51(5), 201–210. <https://doi.org/10.55230/mabjournal.v51i5.2339>
2. **Nabilah Huda, M. H.**, Meekiong, K., Elias, H. & Gawin, D. F. (2023). Preliminary Study of *Nepenthes* in Banjaran Undan, Sarawak, Malaysia. *The Malaysian Forester*, 86(1), 190–199.
3. **Nabilah Huda, M. H.**, Umie Naylisa, M.A., & Meekiong, K. (2023). Die Suche nach Karnivoren in der Undan Range auf Borneo. *Das Taubblatt*, 93(1), 58-69.
4. Meekiong, K., Habibah, S., Umie Naylisa, M.A., **Nabilah Huda, M. H.** Salina, H. & Teo, S.P (eds). (2023). *The Heart of Borneo Series 16: Carnivorous Plants*. Forest Department Sarawak, Kuching, Sarawak. ISBN 978-976-26032-6-9.

Appendix D: Research Grant/Scholarship

1. Year 2020-2021 : Zamalah Siswazah UNIMAS Scholarship
2. Year 2022 : Fundings from The German Carnivorous Plant Society for exploration project in Banjaran Undan, Bau, Sarawak, Malaysia.

Appendix E: Research Permits

Your Ref. :
Our Ref. : SFC.PABC.CO.931 (18)
Date : 3rd February 2020



Nurul Nabilah Huda Binti Mohd Hisham
Faculty of Resource Science and Technology,
University Malaysia Sarawak (UNIMAS),
94300 Kota Samarahan, Sarawak

Dear Sir

PERMISSION TO CONDUCT RESEARCH ON BIOLOGICAL RESOURCES – PERMIT NO. SFC.PABC.CO.931 (17) AND WL13/2020

The application for the above subject matter refers.

2. Enclosed herewith is the permission and approval for your group to conduct research in Sarawak. This approval letter is to be returned to the Controller upon expiry of its validity period.

3. Members of your group are also required to liaise and report to Sarawak Forestry Corporation or Park Warden upon arrival to ensure that the National Parks and Nature Reserves Ordinance 1998 and Wild Life Protection Ordinance, 1998 are complied with accordingly.

Thank you.

ICARE



ZOLKIPLI BIN MOHAMAD ATON
Controller of Wild Life
SARAWAK

SARAWAK FORESTRY Corporation
Lot 218, KCLD, Jalan Tapang, Kota Sentosa, 93250 Kuching
Tel: (+6) 082 610088 Fax: (+6) 082 629744 www.sarawakforestry.com

Your Ref. : 2021010
Our Ref. : SFC.810-4/6/1(2021) - 015

Date : 26 March 2021



Ms. Nurul Nabilah Huda Binti Mohd Hisham
Dr. Qammil Muzzammil Abdullah @ Meekiong Kalu
Ms. Nurul Khaleeda Binti Ridzuan
Ms. Nur Athirah Nabihah Binti Mohamad Mahmud
Ms. Umie Naylisa Binti Mohamad Asmadi
Madam Salasiah Binti Mohamad
Faculty of Resource Science and Technology
Universiti Malaysia Sarawak
94300 Kota Samarahan
Sarawak

Dear Sir/Madam,

Permission to Conduct Research on Biological Resources/Collect Samples of Biological Resources for Research:- Systematic Study Of Genus Nepenthes (Nepenthaceae) In Western Sarawak

Greetings from SFC!

The above subject matter refers.

2. With regards to your application for the above subject, I am pleased to inform that permission is hereby granted for you and your team members to conduct research and collect samples of biological resources within the area as per table below:

Species		Location	Quantity
Scientific Name	Type of Organism		
	Nepenthes Species	• Gunung Gading National Park • Santubong National Park • Bako National Park • Kubah National Park	• Nepenthes species (3 specimen per species)

SARAWAK FORESTRY Corporation

Lot 218, KCLD, Jalan Tapang, Kota Sentosa, 93250 Kuching
Tel: (+6) 082 610088 Fax: (+6) 082 629744 www.sarawakforestry.com

Your Ref. : 2021010
Our Ref. : SFC.810-4/6/1 (2022) - 036
Date : 25 March 2022



Ms. Nurul Nabilah Huda Binti Mohd Hisham
Faculty of Resource Science and Technology
Universiti Malaysia Sarawak
94300 Kota Samarahan, Sarawak

Dear Sir/Madam,

**PERMISSION TO CONDUCT RESEARCH ON BIOLOGICAL RESOURCES – PERMIT
SFC.810-4/6/1 – 035 AND PARK PERMIT NO. WL 14/2022**

Greetings from SFC!

The application for the above subject matter refers.

2. Enclosed herewith is the permission and approval for you and your team member to conduct research in Sarawak. This approval letter is to be returned to the Controller upon expiry of its validity period.
3. Members of your research group are also required to liaise and report to Sarawak Forestry Corporation (SFC) or Park Warden upon arrival at your research sites (Parks) to ensure that the National Parks and Nature Reserves Ordinance 1998 and Wild Life Protection Ordinance, 1998 are complied with accordingly.

Thank you.

I CARE

A handwritten signature in blue ink, reading "Zolkipli Bin Mohamad Aton".

ZOLKIPLI BIN MOHAMAD ATON
Controller of Wild Life and
National Parks & Nature Reserves
SARAWAK
nr/

"NEW FRONTIER IN BIODIVERSITY CONSERVATION"

SARAWAK FORESTRY Corporation
Lot 218, KCLD, Jalan Tapang, Kota Sentosa, 93250 Kuching
Tel: (+6) 082 610088 Fax: (+6) 082 629744 www.sarawakforestry.com