



Faculty of Resource Science and Technology

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

Nurul Nabilah Huda binti Mohd Hisham

**Master of Science
2024**

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

Nurul Nabilah Huda binti Mohd Hisham

A thesis submitted

In fulfillment of the requirements for the degree of Master of Science

(Plant Science)

Faculty of Resource Science and Technology

UNIVERSITI MALAYSIA SARAWAK

2024

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

Date : 20th February 2024

ACKNOWLEDGEMENT

During almost four years of my studies, I unlearned, learned, and relearned a lot of things, both good and bad in the botany world; peoples, works, cultures, attitudes, thoughts, opinions and critiques, experiences, patience, perseverance, passion and interest and so many more. All of this will become my guidance for my future career in botany and life overall. Alhamdulillah to Allah Almighty for giving me the opportunity and strength to keep going in achieving my dreams no matter how hard it may seem. This humble work had involved many efforts from those who had contributed and supported me directly and indirectly. It is impossible to extend enough thanks to those who has been part of my journey.

Thank you to my academic supervisor, Dr Meekiong Kalu, who has been an amazing botany teacher that academically and professionally guided me in completing my master studies. Also, to my co-supervisor, Dr Hashimah Elias for her excellent guidance to help me complete this studies. Not to forget to UNIMAS, for awarding me the Zamalah Siswazah Scholarship for my studies and to the staff of the faculty for their technical help and support.

Special thanks as well to the labmates, seniors, and friends; Khaleeda, Athirah, Naylisa, Haziah, Almunah, Awang Ahmad, Dr Salasiah, Jovita, Aimi, Syasya, Miraadilah, Azimah, Easter, Raihan, Syahida, Norazira, Aisyah Zakeri, Syahirah, Non, Thracesy, Ivy, Aida, Afiqah, Tajul, Farah Wahidah, Farah Zakaria, Sahlinah, Nisa, Allysha, Aliaa, Afifah, and many more names. All of you have been an amazing friend and a mentor to me.

Forever sincere gratitude to my beloved family, especially Mama, Nenek, Atuk, and Cik Nazree, for always supporting me endlessly and be my main pillar in life. To my cat, Putih, thanks for your loyal companionship while burning the midnight oil to work on this thesis.

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 kepelbagaiannya. *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. decurrent 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 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	121
Figure 4.30: Pollen grains of <i>Nepenthes</i> studied. (a) equatorial 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.