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Habitat and edaphic preference of *Rafflesia* R. Br. plant communities in Royal Belum State Park, Perak, Peninsular Malaysia

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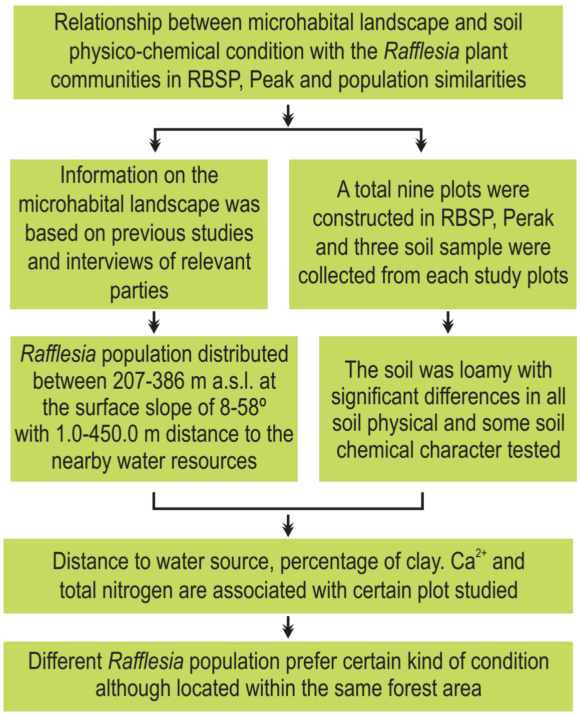
Abstract

Aim: To investigate the relationship between the microhabitat conditions and soil physico-chemical characters of *Rafflesia* plant communities and to determine similarities across *Rafflesia* habitats in Royal Belum State Park, Perak, Peninsular Malaysia

Methodology: The site of *Rafflesia* population and its microhabitat condition was collected by referring to the previous studies, in addition to interviewing the related parties. A plot study was constructed in each *Rafflesia* habitat in Royal Belum State Park, Perak and the soil sample was collected for estimating their characteristics.

Results: *Rafflesia* population is distributed between 207 - 386 m asl, with the surface slope of 8 to 58° and located 1.0-450.0 m from nearby water sources. The percentage of clay has a strong influence in X-Ray and distance to water source affected the habitat in Sg. Ruok-Papan. Ca^{2+} was an important soil component in Sg. Kooi while in Sg. Gadong 2 and Sg. Selantan, nitrogen was the most important soil attribute. The dendrogram reveals Sg. Kooi and Sg. Gadong 1 were the most similar habitats while Sg. Ruok differed significantly in terms of the microhabitat and soil physicochemical conditions tested.

Interpretation: This study shows that different plant communities favoured different conditions in terms of microhabitat condition and the physico-chemical characteristics of soil, despite being located within the same forest range. Since this study covered only small forest range, large sampling size which cover different forest area is needed to come to a conclusion regarding preference of *Rafflesia* plant communities towards its habitat.



Key words: Ecological study, Microhabitat condition, Royal Belum State Park, Soil physicochemical characters

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Introduction

Most taxonomic studies on *Rafflesia* sp. have been conducted in relation to identification of new species. As a holoparasitic plant, *Rafflesia* does not have any photosynthetic system to perform photosynthesis and produce its own food. For survival, protection and nutrient requirement *Rafflesia* entirely depend on its host, which is a liana, known as the *Tetrastigma* sp. (Nais, 2001). Due to these conditions conserving this giant flower requires conserving its habitat, especially the edaphic conditions where the host exists.

Studies have listed several factors that affect the liana growth, including its soil properties such as soil moisture content (Addo-Fordjour *et al*., 2014; DeWalt *et al*., 2006; Ibarra-Manriquez and Martinez-Ramos, 2002; Schnitzer, 2005) and soil nutrient content (Chettri *et al*., 2010; DeWalt *et al*., 2006; Gentry, 1991; Laurance *et al*., 2001; Malizia *et al*., 2010; Swaine and Grace, 2007). Addo-Fordjour *et al*. (2014), DeWalt *et al*. (2006) and Ibarra-Manriquez and Martinez-Ramos (2002) discovered that the liana diversity, species richness and abundance increased proportionally with the soil moisture content. However, this result is contradictory to Schnitzer (2005). In terms of nutrient content, Malizia *et al*. (2010) found that the liana abundance was increased with the phosphorus content. The soil pH and magnesium content were found to influence the basal area and diameter of the liana (Addo-Fordjour *et al*., 2014). While Homeier *et al*. (2010) stated that the available nitrogen affects the liana abundance, and there was a positive effect on the exchangeable calcium and negative effect on the exchangeable aluminium towards the liana density.

However, this knowledge cannot be solely accepted since this information focuse on lianas in general, which have habitats and communities that differ from the *Rafflesia* plant communities. To date, only Pranata *et al*. (2019) has studied specifically on *Rafflesia* plant communities in relation to soil condition. Nevertheless, this information is insufficient to conclude the specific edaphic condition that becomes the preference for *Rafflesia* plant communities.

This information is crucial especially given that the *Rafflesia* habitat attracts significant tourist numbers which threatens to disturb its growth. This situation can be seen in Royal Belum State Park, Perak, Peninsular Malaysia which serves as home to three *Rafflesia* species, namely *Rafflesia cantleyi, R. kerrii* and *R. azlanii*. Due to ecotourism, the population and distribution of *Rafflesia* has decreased due to human interruption, and natural disturbances of course (Farah Khaliz *et al*., 2018; Nasihah *et al*., 2016).

To date, only a handful of studies have been conducted on *Rafflesia* within the Royal Belum State Park which focus on the distribution (Farah Khaliz *et al*., 2018; Nur Hayati *et al*., 2020) and physiology (Farah Khaliz *et al*., 2018). Unfortunately, no study has so far focused on the relationship between the host and its soil condition. Since soil provides nutrients required by the majority of vegetation for their survival, this study is crucial to conserve the *Rafflesia* population in Royal Belum State Park. Therefore, this study was conducted to determine the relationship between the *Rafflesia* plant communities with the microhabitat condition and edaphic factors within the *Rafflesia* habitat in Royal Belum State Park.

Materials and Methods

Study area : The study area is one of the most popular ecotourism sites in Peninsular Malaysia located at the upper part of Belum-Temengor Forest Complex. Royal Belum State Park covers approximately 90% of the Belum-Temengor Forest Reserve, covering total area of 117,500 ha. Nine *Rafflesia* populations have been recorded in Royal Belum State Park, and a total plot area of 1.13 ha plot has been constructed. The plot covers the *Rafflesia* population in the following sites : Sg. Gadung 1 (SG1), Sg. Gadung 2 (SG2), X-Ray (XR), Sg. Ruok (SR), Sg. Ruok-Papan (SRP), Sg. Kooi (SK), Sg, Kenarong (SKG), Sg. Tiang (ST) and Sg. Selatan (SS).

Microhabitat condition: This study included information pertaining to altitude, slope degree and distance of the population to nearby water resources. This information was based on Nur Hayati *et al*. (2020) with additional information gathered by interviewing the communities in Royal Belum State Park.

Plot set-up and soil collection: A circular-shaped plot of 5m radius was constructed from the host in each *Rafflesia* population in Royal Belum State Park. Three replicates of soil samples were then collected with a soil auger with 20 cm depth in each study plot. The soil samples were later stored in plastic bags and secured tightly.

Soil analysis: The soil physical properties included the soil texture, water content and the organic matter content. Physical classification of soils using soil texture triangles (USDA, 1960). Soil water content was measured by subtracting the weight of the dry soil from the weight of the moist soil, and then dividing by the weight of the dry soil. While to estimate the amount organic matter present in a soil sample is by measuring the weight lost by an oven-dried (105°C) soil sample when it is heated to 400°C; this is known as 'loss on ignition', essentially the organic matter is burnt off(Avery and Bascomb,1982).

The parameters for the chemical properties analyses including the soil pH, electrical conductivity (EC), cation exchange capacity (CEC) and available nutrients were measured. The pH of the soil was tested using 1:2.5 soil to water ratio (Metson, 1956), while the soil EC was measured using a conductivity metre. In determining CEC, the sample was analysed using the summation method through ICP-MS (Inductively Coupled Plasma-Mass Spectrophotometer) machine. For the available nutrients of phosphorus, it was determined through the available methods and tested using Ultraviolet (UV) Spectrophotometer, while potassium, magnesium and calcium were determined through ICP-MS.

Data analyses: The collected samples were analyzed for major physical and chemical soil quality parameter like soil pH, electricalconductivity (EC), organic carbon (OC), available nitrogen (N), phosphorus (P), potassium (K). One-way ANOVA of IBM SPSS Statistics version 22 were used for analyzingthe physical and chemical soil data, while Principal Canonical Analysis (PCA)and Cluster Analyses were conducted using PaleontoligalStatistic (PAST) version 2.14 to ascertain the preference of hostregarding topography and soil elements tested.

Results and Discussion

The study is a continuation of Nur Hayati *et al.* (2020) which this study describes the microhabitat, and physical and chemical characteristics of the soil. Data were added regarding the distance of the host tothe nearby water source for Sg. Kooi and Sg. Kenarong. Table 1 shows complete information regarding the microhabitat conditions of *Rafflesia* populations in Royal Belum State Park, Perak.

Through this study, the *Rafflesia* plant communities in Royal Belum State Park were found to grow above 207 m a.s.l. with the maximum slope angle of 58°. The farthest distance of the host to the water source was 450.0 m in Sg. Kenarong. However, Nasihah *et al*. (2016) in Lojing Highlands, Kelantan and Pranata *et al*. (2019) in Padam Gadang, West Sumatra, reported that the *Rafflesia* population existed at much higher elevations of 800-1200 m a.s.l. and 800-1024 m a.sl., respectively. However, this range depended on the *Rafflesia* species existing within that particular area (Nais, 2001). While in terms of distance to the water source, this study showed a quite high range of *Rafflesia* population distance to its nearby water source when compared to Pranata *et al*. (2019) who stated that *Rafflesia* population in Padam Gadang, West Sumatra ranged between 3.0-27.8 m from the water source.

The *Rafflesia* habitat in the Royal Belum State Park is mainly characterised by loam soil which is able to retain more nutrients and humus, and has better infiltration and drainage compared to clay soils (Osman, 2013). Most tree species grow well in sandy loam to clay loam texture due to adequate supply water, air, and nutrients. About three out of nine *Rafflesia* habitats (33.33%) were represented with loam soil texture, two habitats with sandy clay loam (22.22%), and one habitat with silty clay loam (11.11%), clay loam (11.11%), sandy loam (11.11%) and clay (11.11%) (Table 2). This study is similar to Nasihah *et al.* (2016) except that there is a percentage difference for each soil texture.

The soil texture of Royal Belum State Park was largely dominated by the sandy texture (17.94 to 69.76%), followed by silt (14.93 to 42.10%) and clay (15.31 to 47.78%), respectively (Table 2) with significant figures for all these soil textures among the studied plots ($p < 0.05$).

The average percentage of organic matter content of the study ranged from low (2.30%) to medium (8.17%) (p=0.004) (Table 2). Landon (1991) and Sharu *et al*. (2013) stated that 4% to 10% of organic matter content is considered as average. However, it was quite high compared to that reported by Nasihah *et al*. (2016) in Lojing Highland, Kelantan with organic content ranging from 2.36% to 4.19%.

Table 2 shows that the soil moisture content within the study area ranged from 3.81% to 7.13%. The highest soil humidity content was found in the habitat of *Rafflesia* in Sg. Selatan characterised by clay-soil type, followed by Sg. Ruok-Papan with clay loam texture. This could be a certained to the property of clay that has little space which enable the soil to retain more water compared to other soil textures (Othman, 2013).

The soil chemical properties of nine study plots is shown in Table 3. According to McCauley *et al*. (2017), the pH value of forest soil is in the range of 3-5, whereas Othman and Shamshuddin (1982) reported that the typical pH value of tropical rainforest in Peninsular Malaysia is between 4.5-5.5. Both statements showed that forested area, especially in Peninsular Malaysia exists in acidic soil condition. This condition is in line with the soil pH of nine study plots at Royal Belum State Park, with the average values ranging between 3.51 to 4.29. Furthermore, the pH value showed significant difference ($p \leq 0.01$) between the sites. Pranata *et al*. (2019) reported that the *Rafflesia* population in Padam Gadang, West Sumatra, had a much higher pH value, ranging from 7.0-7.8. This difference might be due to different environmental conditions which affecs the soil composition since it is located at high elevations in West Sumatra.

The electrical conductivity within the nine *Rafflesia* habitats in Royal Belum State Park ranged from 1.85 to 2.47 (Table 3). Referring to Schoeneberger *et al*. (2002), these values were within the range of non-saline (< 2 mS cm^{-1}) to mild saline (2 to less than 4 mS cm^{-1}). According to Shamshuddin (1981), a higher index of electrical conductivity may disturb the development and growth of plants. Smith and Doran (1996) suggested that EC value ranging from 0 to 1 mS cm^{-1} indicates good soil health, while if the range is above than 1 to 2 mS cm^{-1}, it will reduce the growth of salt-sensitive plants and disrupt the microbially mediated processes of nitrification and denitrification. They also stated that cation in solution is always balanced with the cation in soil particles. Cation in the solution can be taken up by the roots through osmosis. The nutrient will be lost slowly but will be replaced by the minerals from other sources. To achieve the electrical balance, the cation is adsorbed by the clay minerals

Table 1: Microhabitat conditions of *Rafflesia*'s host in the Royal Belum State Park, Perak

Sites	Elevation (a.s.l.)	Slope (°)	Distance to water source (m)
Sg. Gadong 1	291	40	13.0
Sg. Gadong 2	386	50	11.5
Sg. Ruok-Papan	237	24	6.4
Sg. Ruok	207	8	1.0
Sg. Tiang	347	38	9.9
Sg. Kooi	360	58	20.0
Sg. Kenarong	295	8	450.0
X-Ray	270	56	9.0
Sg. Selantan	363	46	40.0

Table 2 : A total of mean (±SD) soil characteristics in study sites

Sites	Sand (%)	Silt (%)	Clay (%)	Soil texture	Organic matter (%)	Soil moisture (%)
Sg. Gadong 1	17.94±1.00^{e}	42.10±2.88^{a}	39.96±3.02^{ab}	Silty clay loam	4.60±0.42^{abc}	5.11±0.84^{bc}
Sg. Gadong 2	45.83±3.50^{bc}	33.23±1.47^{bc}	20.94±2.05^{cd}	Loam	8.17±4.30^{a}	5.14±0.56^{bc}
Sg. Ruok-Papan	41.73±3.91^{c}	24.11±0.47^{de}	34.16±3.49^{b}	clay loam	4.32±0.78^{abc}	6.17±1.09^{ab}
Sg. Ruok	69.76±1.95^{a}	14.93±0.87^{f}	15.31±1.16^{d}	Sandy loam	2.83±0.52^{bc}	3.81±0.30^{c}
Sg. Tiang	51.50±4.61^{b}	25.13±0.82^{d}	23.38±4.48^{cd}	Sandy clay loam	2.30±0.19^{c}	4.50±0.40^{bc}
Sg. Kooi	60.91±1.78^{a}	14.97±0.29^{f}	24.12±1.50^{c}	Sandy clay loam	6.93±0.59^{ab}	5.16±0.25^{bc}
Sg. Kenarong	44.20±2.43^{bc}	31.15±0.87^{c}	24.65±1.56^{c}	Loam	4.93±0.43^{abc}	5.33±1.02^{abc}
X-Ray	38.22±2.42^{cd}	36.67±0.65^{b}	25.11±2.03^{c}	Loam	4.08±0.57^{abc}	5.66±0.59^{abc}
Sg. Selantan	31.62±5.66^{d}	20.59±0.86^{e}	47.78±5.00^{a}	Clay	5.81±0.45^{abc}	7.13±0.50^{a}
p-value	9.82×10^{-12}	2.39×10^{-15}	1.96×10^{-9}	-	3.68×10^{-3}	9.17×10^{-4}

Values with similar alphabet are not significantly different with p > 0.05 based on Tukey HSD t.

(Othman and Shamshuddin, 1982).

Cation exchange capacity is an important soil chemical property. It as it describes soil fertility, nutrient-holding capacity and the ability to control groundwater from cation contamination (Khairil *et al*., 2014). The average value of CEC of soil of study areas ranged from 2.88 to 7.76 meq 100 g^{-1}, with no significant difference between sites ($p > 0.05$). According to Esu (1991) and Sharu *et al*. (2013), the CEC values recorded were considered low to medium. In addition, Shamshuddin (1981) suggested that tropical soil requires an effective CEC of > 4 meq 100 g^{-1} which is possible due to high weathering conditions.

According Othman and Shamsuddin (1982) stated that tropical soils vary greatly in their principal chemical and physical properties, such as parent material, soil structure, drainage regime, and age. Variations in soil properties play an important role in the different types of tropical forest ecosystems. The plants require macronutrients for growth and without sufficient supply of these nutrients, the plant cannot grow well or may die. Table 3 shows that most of the study plots had the highest potassium content compared to other available macronutrients. The highest value (5347.14 µg g^{-1}) was recorded in Sg. Tiang. This result was very high compared to Nasihah *et al*. (2016) who found that the available potassium content within their study areas ranged between 0.11 µg g^{-1} to 0.26 µg g^{-1}. However, the results showed no significant difference ($p > 0.05$) in this available macronutrient across the study plots at Royal Belum State Park.

The highest mean value of phosphorus (5.71 µg g^{-1}) reported in Sg. Kooi while the lowest average value was recorded in X-Ray (1.15 µg g^{-1}). Although the gap between the highest and lowest mean values for phosphorus content was only 4.56 µg g^{-1}, One-way ANOVA analysis showed that there was a very significant difference between the study plots ($p \leq 0.001$) (Table 3). Previous studies have reported different ranges for phosphorus content. Several factors affect the phosphorus concentration in soil, including the adsorption and absorption processes by plants, use of fertilisers and decomposition of inorganic phosphorus (Frossard *et al*., 2000). Friesen *et al*. (1980) also stated that the pH value of soil also affects phosphorus content, where the increase in pH values will reduce phosphorus content. In addition, organic matter content also affects the macronutrient values of soil (Othman and Shamshuddin, 1982).

The results showed the highest magnesium level was found in soil samples of Sg. Ruok, while the lowest was observed in Sg. Ruok-Papan (Table 3). There were also significant differences ($p < 0.05$) in Mg content between the plots.

Table 3 : Soil chemical properties of nine study plots and the *p*-value based on One-way ANOVA at RBSP, Perak

Parameter	SG 1	SG 2	SRP	SR	ST	SK	SKG	XR	SS	*p*-value
pH	3.51 ± 0.03^{c}	3.59 ± 0.16^{bc}	3.53 ± 0.05^{c}	3.68 ± 0.06^{bc}	3.60 ± 0.21^{bc}	3.73 ± 0.10^{bc}	4.29 ± 0.12^{a}	3.88 ± 0.10^{b}	3.76 ± 0.10^{bc}	5.58×10^{-6}
EC (mS cm^{-1})	2.40 ± 0.09^{ab}	2.47 ± 0.12^{a}	2.26 ± 0.03^{bc}	2.23 ± 0.07^{bc}	2.25 ± 0.02^{bc}	2.45 ± 0.05^{a}	2.38 ± 0.02^{ab}	2.16 ± 0.02^{c}	1.85 ± 0.08^{d}	1.92×10^{-8}
Exchangeable cation (meq 100g^{-1})										
Ca^{2+}	0.22 ± 0.02^{bcd}	0.42 ± 0.25^{bc}	0.11 ± 0.11^{d}	0.19 ± 0.01^{cd}	0.22 ± 0.09^{bcd}	0.49 ± 0.03^{b}	0.91 ± 0.08^{a}	0.47 ± 0.08^{bc}	0.25 ± 0.04^{bcd}	8.99×10^{-7}
Mg^{2+}	0.32 ± 0.20^{bc}	0.72 ± 0.48^{ab}	0.05 ± 0.05^{c}	0.21 ± 0.07^{bc}	0.12 ± 0.02^{bc}	0.53 ± 0.20^{bc}	1.22 ± 0.17^{a}	1.26 ± 0.25^{a}	0.52 ± 0.10^{bc}	4.88×10^{-6}
Na^{+}	0.62 ± 0.06^{a}	0.61 ± 0.02^{a}	0.37 ± 0.38^{a}	0.82 ± 0.14^{a}	1.79 ± 1.83^{a}	0.62 ± 0.02^{a}	0.70 ± 0.09^{a}	0.61 ± 0.01^{a}	0.61 ± 0.01^{a}	3.17×10^{-1}
K^{+}	1.29 ± 0.35^{a}	1.63 ± 0.59^{a}	0.38 ± 0.35^{a}	0.86 ± 0.24^{a}	4.23 ± 5.61^{a}	2.00 ± 0.36^{a}	0.91 ± 0.01^{a}	1.10 ± 0.04^{a}	1.00 ± 0.05^{a}	4.28×10^{-1}
Al^{3+}	4.10 ± 0.60^{a}	1.43 ± 0.60^{b}	1.33 ± 0.40^{b}	0.83 ± 0.21^{bc}	1.00 ± 0.17^{bc}	0.83 ± 0.12^{bc}	0.17 ± 0.06^{c}	0.93 ± 0.42^{bc}	1.37 ± 0.12^{b}	1.10×10^{-8}
H^{+}	0.50 ± 0.10^{a}	0.50 ± 0.40^{a}	0.63 ± 0.25^{a}	0.37 ± 0.06^{a}	0.40 ± 0.26^{a}	0.33 ± 0.06^{a}	0.27 ± 0.06^{a}	0.37 ± 0.06^{a}	0.50 ± 0.17^{a}	4.80×10^{-1}
CEC	7.06 ± 0.42^{a}	5.31 ± 0.30^{a}	2.88 ± 0.80^{a}	3.28 ± 0.35^{a}	7.76 ± 7.41^{a}	4.80 ± 0.23^{a}	4.18 ± 0.17^{a}	4.74 ± 0.16^{a}	4.24 ± 0.04^{a}	3.30×10^{-1}
Available nutrients (µg g^{-1})										
N	0.57 ± 0.11^{abc}	0.59 ± 0.19^{ab}	0.61 ± 0.11^{ab}	0.20 ± 0.06^{c}	0.28 ± 0.13^{bc}	0.62 ± 0.04^{ab}	0.19 ± 0.03^{c}	0.68 ± 0.26^{a}	0.63 ± 0.07^{ab}	3.90×10^{-4}
P	1.97 ± 0.25^{bc}	3.85 ± 1.65^{ab}	2.40 ± 0.15^{bc}	2.14 ± 0.57^{bc}	2.40 ± 0.11^{bc}	5.71 ± 0.70^{a}	2.60 ± 0.67^{bc}	1.15 ± 0.48^{c}	3.27 ± 0.70^{b}	3.319×10^{-5}
K	496.31 ± 395.53^{a}	344.40 ± 137.84^{a}	116.25 ± 6.30^{a}	131.90 ± 27.40^{a}	5347.14 ± 8889.55^{a}	479.35 ± 168.29^{a}	186.85 ± 5.39^{a}	230.51 ± 17.55^{a}	193.30 ± 12.35^{a}	6.43×10^{-1}
Mg	93.25 ± 42.05^{a}	200.55 ± 113.61^{a}	34.35 ± 12.23^{a}	1085.84 ± 1763.05^{a}	502.49 ± 798.12^{a}	127.66 ± 28.08^{a}	321.93 ± 26.22^{a}	292.42 ± 59.56^{a}	117.03 ± 21.91^{a}	4.81×10^{-1}
Ca	60.33 ± 14.99^{a}	117.42 ± 80.23^{a}	53.23 ± 15.05^{a}	3053.45 ± 5174.34^{a}	69.59 ± 11.40^{a}	143.94 ± 29.30^{a}	237.15 ± 9.84^{a}	113.58 ± 29.03^{a}	57.79 ± 4.53^{a}	4.85×10^{-1}

Values are mean ± SD; Values with similar alphabet were not significantly different with $p>0.05$ based on Tukey HSD test. EC = electrical conductivity, Ca^{2+}= exchangeable calcium, Mg^{2+}= exchangeable magnesium, Na^{+}= exchangeable sodium, K^{+}= exchangeable potassium, Al^{3+}= exchangeable aluminium, H^{+}= exchangeable hydrogen, CEC = cation exchange capacity, N = nitrogen, P = phosphorus, K = potassium, Mg = Magnesium, Ca = Calcium, SG 1 = Sg. Gadong 1, SG 2 = Sg. Gadong 2, SRP = Sg. Ruok-Papan, SR = Sg. Ruok, ST = Sg. Tiang, SK = Sg. Kooi, SKG = Sg. Kenarong, XR = X-Ray, SS = Sg. Selantan

Furthermore, the Ca content between the plots ranged between 53.23 to 3053.45 µg g^{-1} that showed no significant differences ($p > 0.05$) between the study plots (Table 3).

Fig. 2 shows three distinct groups based on the physical properties studied. The first group located in positive PC-1 and PC-2 showed that Sg. Gadong 2 was associated with the elevation, slope and soil organic content. The second group in positive PC-1 and negative PC-2 revealed soil moisture, percentage of silt and clay, and distance of the host to water source does affect X-Ray, Sg. Gadong 1, Sg. Ruok-Papan and Sg. Kenarong. While third group in positive PC-2 showed Sg. Tiang has a relationship with the percentage of the sand. This third group supported by Nasihah *et al*. (2016) found the percentage of sand directly affected the *Tetrastigma* sp. in Lojing Highland, Kelantan. Since no similar pattern in the plot distribution in relation to soil physical factors was observed, it shows that different populations were associated with certain soil physical conditions despite being located within the same forest area.

There was an unclear grouping between the soil chemical characters with the plots (Fig. 3). The PCA ordination shows that Sg. Kooi was highly correlated with exchangeable calcium and pH. This result is similar to Nasihah *et al*. (2016) who stated that the soil pH affected the *Tetrastigma* sp. and *R. kerrii* in Kelantan. This study also found that Sg. Gadong 2 and Sg. Selantan were associated with total soil nitrogen while Sg. Gadong 1 related to exchangeable aluminium (Al^{3+}) and hydrogen (H^{+}). These results were similar to the soil physical characteristics which showed that each population had an exclusive preference for soil characteristics.

Cluster analysis was performed to test the similarity between *Rafflesia* habitats in terms of microhabitat condition and soil physico-chemical characteristics. The analysis indicated that habitat Sg. Kooi and Sg. Gadong 1 showed the highest similarity, followed by Sg. Ruok-Papan and Sg. Selantan (Fig. 4). Only threephysical characters (soil moisture, sand and organic matter) and one chemical (Mg^{2+}) character of soil weresignificantly different ($p < 0.05$) for Sg. Kooi and Sg. Gadong 1. Additionally, soil moisture, EC, exchangeable Na^{+} and Mg^{2+} and available P were same between Sg. Kooi and Sg. Gadong.

Sg. Ruok showed the least habitat similarity compared to other *Rafflesia* habitat in this study. Sg. Ruok recorded the lowest elevation level and slope angle, and its location was nearest to the water source as compared to other study plots in Royal Belum State Park. Sg. Ruok also recorded the highest percentage of sand but the lowest for clay and soil moisture, in addition to lower

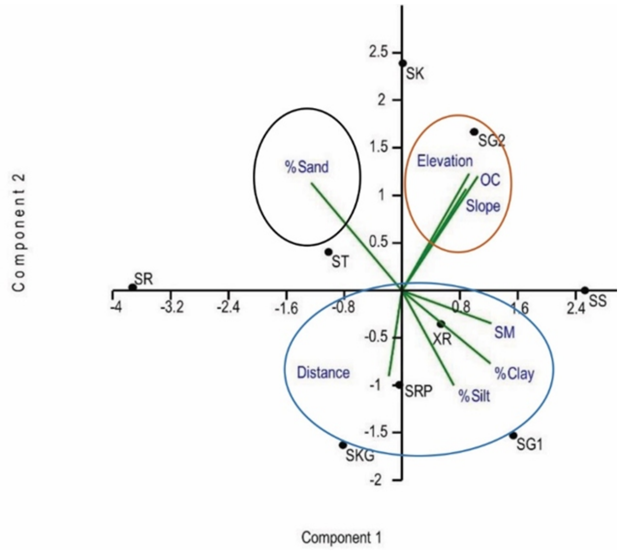

Fig. 2: PCA ordination of microhabitat condition and soil physical characters in the habitat of *Rafflesia* host in RBSP, Perak (Note: Slope = Slope angle, Distance = Distance to the water source, SM = soil moisture, OC = organic content, SG1 = Sg. Gadong 1, SS = Sg. Selantan, XR = X-ray, SRP = Sg. Ruok-Papan, SKG = Sg. Kenarong, SG2 = Sg. Gadong 2, ST = Sg. Tiang, SK = Sg. Kooi, SR = Sg. Ruok).

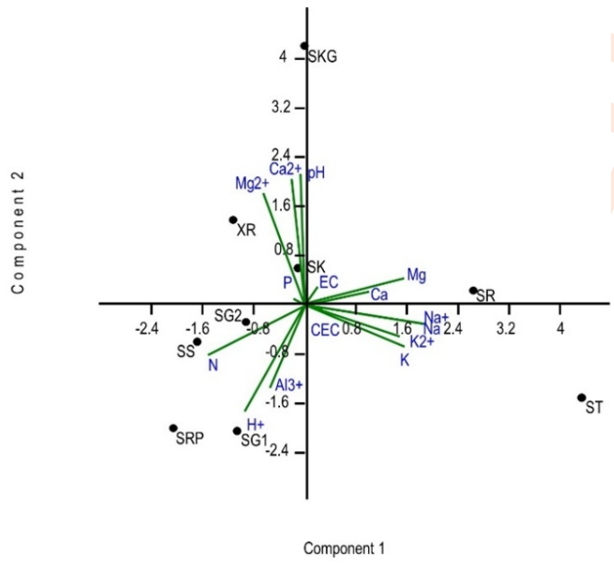

Fig. 3: PCA ordination of soil chemical characters in the habitat of *Rafflesia* host in RBSP, Perak (EC = electrical conductivity, N = nitrogen, P = phosphorus, K = potassium, Mg = Magnesium, Ca = Calcium, Ca^{2+}= exchangeable calcium, Mg^{2+}= exchangeable magnesium, Na^{+}= exchangeable sodium, K^{+}= exchangeable potassium, Al^{3+}= exchangeable aluminium, H^{+}= exchangeable hydrogen, CEC = cation exchanged capacity, SR = Sg. Ruok, SKG = Sg. Kenarong, XR = X-ray, SG2 = Sg. Gadong 2, SS = Sg. Selantan, SRP = Sg. Ruok-Papan, SK = Sg. Kooi, SG1 = Sg. Gadong 1, ST = Sg. Tiang).

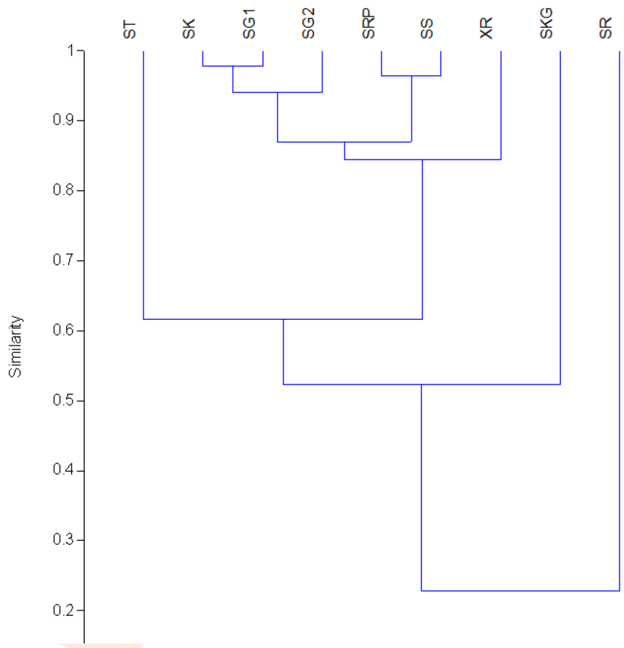

Fig. 4 : Habitat similarity based on the correlation cluster analysis for *Rafflesia* population in RBSP, Perak (ST = Sg. Tiang, SK = Sg. Kooi, SG1 = Sg. Gadong 1, SG2 = Sg. Gadong 2, SRP = Sg. Ruok-Papan, SS = Sg. Selantan, XR = X-ray, SKG = Sg. Kenarong, SR = Sg. Ruok).

organic content. This indicates that Sg. Ruok was the least fertile plot as high sand, and low clay content caused water to leach easily, and fewer nutrients were stored. In terms of soil chemical characters, Sg. Ruok also recorded a low nitrogen content but had the highest magnesium and calcium content compared to others.

This study reveals that the *Rafflesia* population in Royal Belum State Park prevail existed in the slope area of the lowland forests, mostly located close to water resources. It was also found that the *Rafflesia* population grew in loamy soil in acidic condition and medium soil organic content. The analysis revealed that different plant communities favoured different microhabitat and soil physico-chemical conditions, even though located within the same forest range. This condition does lead to the aggregation of *Rafflesia* population in Royal Belum State Park, Perak for habitat similarity analysis.

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Add-on Information

Authors' contribution : A.K.N. Hayati: Graduate Research Assistant; **K. Shamsul:** Main supervisor; **W.A.W. Juliana:** Co-supervisor; **F.S. Mohd Taib:** Contributed in statistical analysis, **M.N. Shukor:** Project Leader; **M.H. Shahril and E.A. Filza:** Representatives of TNB Research (TNBR) for Research Fund.

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