

MORPHOLOGICAL VARIATION AND GEOGRAPHICAL DISTRIBUTION OF A NEWLY RECORDED *RAFFLESIA ZOLLINGERIANA* (RAFFLESACEAE)

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The objectives of this study were to carry out a morphological comparison of a newly recorded *Rafflesia zollingeriana* in Papring, Northeastern Banyuwangi, East Java, and to examine the biophysics of the habitat of the species. The *R. zollingeriana* of Papring displayed no window, and its tuberculate ramenta occupied the inner surface of the diaphragm and perigone tube. The specimens of Papring varied from three other localities with respect to their smaller flowering sizes, diaphragm, and the dark orange or red maroon colouring of the perigone lobes and diaphragm. The annulus of the Papring *R. zollingeriana* has a distinctive interior with a less developed or less distinctive exterior annulus. Its host is *Tetrastigma rafflesiae*, *T. dichotomum* and *T. papillosum*. The geographical range of the species is fragmented. Its presence is vital for increasing the numbers of existing local populations, and the future survivorship of the species.

Keywords: Banyuwangi, parasite plant, geographical range, *Tetrastigma*

INTRODUCTION

The species *Rafflesia* is unique in appearance, size and physiognomy. All its members are endophytic holoparasitic plants infecting the species of *Tetrastigma* (Vitaceae). Unlike the other plants, *Rafflesia* do not have any form of leaves, trunks, or true root system, and are attached to their hosts through haustorium. The only visible plant organs are the flower buds or the fleshy opening flower with its rotten meat odour (Meijer 1997). The study of *Rafflesia* is still required to reveal its biology. Beaman et al. (1988) and Emmons et al. (1991) respectively provide comprehensive information on the pollination biology and dispersal mechanism of the species.

The geographical range of *Rafflesia* species is limited to South-East Asia, namely, southern Thailand, the Philippines, Malaysia and Indonesia, specifically Sumatera, Kalimantan and Java. There are 38 recorded *Rafflesia* (Siti-Munirah et al. 2020), and 15 of these are found

in Indonesia. Unfortunately, not all *Rafflesia* species have their conservation status listed by the International Union for Conservation of Nature (IUCN). In the latest IUCN Red List of Threatened Species, only *R. magnifica* has been assessed for its conservation status and classified as Critically Endangered (CR). South-East Asian scientists have developed their classifications based on criteria used by IUCN. For example, Nais (2001) put nine species of *Rafflesia* into the Vulnerable category (VU), and one species into CR. Susatya (2011) categorise all Indonesian species as CR, except for *R. arnoldii*, which is rated as VU. Among Indonesian *Rafflesia*, *R. rochussenii*, *R. patma*, and *R. zollingeriana* are exposed to highly fragmented, isolated habitats, rapid climate change, and constant threats from human intrusion on surrounding habitats.

Rafflesia zollingeriana is one of the most widely studied *Rafflesia*. These studies have examined

its population (Hikmat 2006, Lestari et al. 2014, Maezulpah et al. 2019), geographical distribution (Lestari et al. 2014), habitat (Laksana et al. 2018, Maezulpah et al. 2019), insect visitation (Masduki et al. 2019), flower predation (Kusuma et al. 2018), morphological variation (Lestari & Susatya 2022), genetics (Kusuma et al. 2022), and conservation (Lestari et al. 2014). Mt. Watangan, Jember is the site where a holotype specimen of *R. zollingeriana* was collected in 1918 (Koorders 1918). Lestari et al. (2014) reported 17 different sites of *R. zollingeriana* within Meru Betiri National Park in the District of Jember. With this report, the geographical distribution of the species was then extended 40 km to the east from Watangan Mountain. At that time, it was believed the geographical distribution of the species was limited to the Jember region.

The geographical range became larger than previously believed when another two flowering *Rafflesia* were reported. In July 2017, a group of conservation volunteers reported flowering *R. zollingeriana* at Tempursari, Lumajang District within a protected area of Lumajang Forest Management Unit. Another sighting of *Rafflesia*

was recorded at Mt. Lincing, Pasirian, Lumajang District (Lestari & Susatya 2022). These last two locations were respectively 60 and 40 km west of Mt. Watangan. All these three reported sites were in the southern parts of Jember, Banyuwangi, and Lumajang districts. Recently, a new sighting of a flowering *Rafflesia* was reported at Papring, Banyuwangi in October 2021, and was 150 km to the east of Mt. Watangan. Watangan, Meru Betiri, Tempursari, Lincing, and Papring habitats are fragmented forests, and isolated from each other (Figure 1) (Wahyuni et al. 2021).

The fragmented geographical range of the species is important in terms of its morphological variation and ecology (Kusuma et al. 2022, Lestari & Susatya 2022). Individual *Rafflesia* living in fragmented and isolated habitats have been known to keenly adapt to local environments and can often be expected to display a unique genetic makeup. Therefore, the genetic diversity of the population at each site will be important for the future survival of the species. Kusuma et al. (2022) found that *R. zollingeriana* has low genetic diversity, and any new available ecological information is valuable

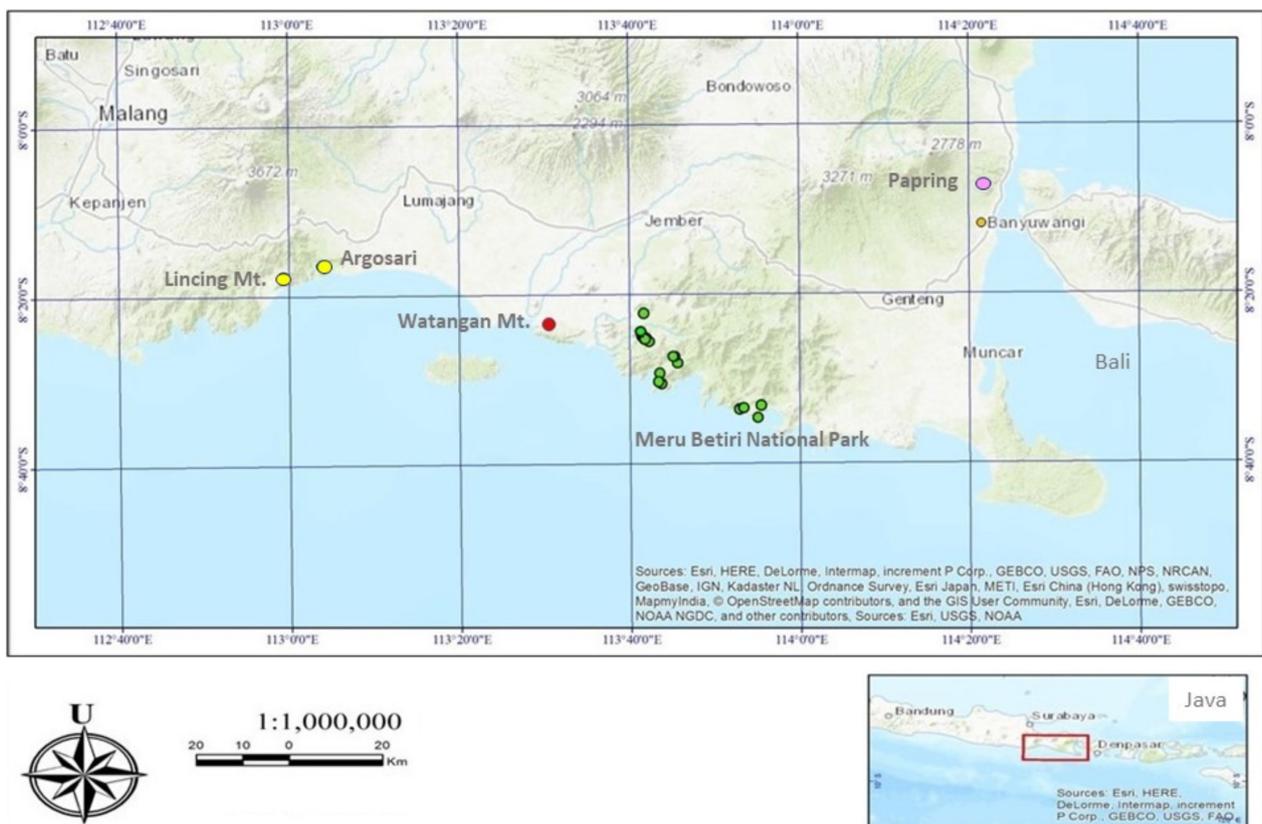


Figure 1 The known geographical distribution of *Rafflesia zollingeriana* at East Java, Indonesia; Mt. Lincing and Argosari, Lumajang; Mt. Watangan, Jember; Meru Betiri National Park; and Papring, Banyuwangi

for conservation purposes. Thus, this study was aimed at conducting morphological comparisons among known flowering *R. zollingeriana*, and its geographical range.

MATERIALS AND METHODS

The research site is within a forest conservation area of the Northern Banyuwangi Forest Management Unit, and is located at Papring Village, Kalipuro, 11 km northeastern of the city of Banyuwangi. The climate of the site is categorised as C3 using the Oldeman classification system, with the average annual rainfall reaching up to 1416 mm year⁻¹. Monthly rainfalls of more than 100 mm occur from November to March (Nuryadi & Agustiarini 2018). Dry months with rainfalls lower than 100 mm occur from April to October. The research site is hilly with a regosol soil type (Sandi et al. 2011). The site also has hilly terrains with moderate slopes of between 16–30%. The vegetation is mixed-secondary forests with bamboo as the dominant species. An exploratory survey was carried out in October 2022 to record flower buds, collect host plant *Tetrastigma* for herbarium specimen, and record environmental conditions. Each flowering *Rafflesia* was photographed and its detailed morphological characters were documented. The morphological analysis was carried out by comparing morphological data of flowering *R. zollingeriana* from the research site with those from Mt. Lincing, Meru Betiri National Park, and Tempursari localities. The morphological data from the last three localities followed Lestari and Susatya (2022). Herbarium specimens of the host plant were identified at Herbarium Bogoriense.

RESULTS AND DISCUSSION

Rafflesia zollingeriana has long been enthusiastically discussed among taxonomists with regard to its status as either a distinct species or a variant form of *R. patma*. Both species are far from each other and separated by a distance of almost 600 km. The geographical range of *R. zollingeriana* is in the eastern part of East Java Province, while *R. patma* is in Pangandaran, West Java Province (Meijer 1997, Susatya 2011). The morphological similarity between these two species has often led to the ambiguity surrounding the taxonomic status of the species. Koorders (1918) provided a long and interesting discussion on the

taxonomical ambiguity of the species. Koorders (1918) mentioned that Teijsmann and Zollinger initially considered specimens collected from Jember and Banyuwangi of East Java as *R. patma*, but without morphological comparisons. Furthermore, a specimen collected in 1895 from Jember was provisionally identified as “*Rafflesia patina*” which was incorrectly spelled *R. patma* (Koorders 1918). These two readings may have led to later scientists considering all specimens either from Jember or Banyuwangi as *R. patma*, until Koorders (1918) described a specimen from Mt. Watangan as a distinct species. However, Meijer (1997) put the species as a variant form of *R. patma* of East Java. He believed the morphological difference between the two species was insignificant. The only differences were the almost absence of ramenta in the base of the perigone tube and the smaller size of *R. zollingeriana* than *R. patma*. Zuhud et al. (1998), Nais (2001), Susatya et al. (2017) furthermore considered *R. zollingeriana* as a distinct species based on size differences, annulus structure, and ramenta distribution. Lestari and Mahyuni (2021) finally concluded that the two species were two distinctively different species. Following is the detailed description of *R. zollingeriana* at Papring locality which parasitises *Tetrastigma rafflesiae*, *T. dichotomum* and *T. papillosum*.

Male. Mature buds are almost circular or pentagon in shape and 16–17 cm in diameter. *Fully opening flowers* measure 31–34 cm in diameter. **Perigone** has 5 lobes and measures 9.3–12.6 cm at its longest, and 12.4–15.6 cm at its widest, dark orange or red maroon colour (Figures 2d, Figure 3 a). **Warts** are whitish orange or creamy white, numerous, small sizes close to the margin and becoming larger towards the centre of the lobe, denser towards the diaphragm, large rectangular or circular warts 4.3–19.8 mm surrounded with small rectangular or circular warts of 2.3–3.3 mm in the centre of the lobes (Figure 3a). **Diaphragm** 12–17 cm in diameter, convex towards the aperture, 2.62–3.22 cm wide (Figure 3b), aperture 7.0–7.5 cm wide (Figure 3c), the proportion of the aperture to the diameter 45–48%, numerous warts, irregular shape with diameter 2.0–3.01 mm, creamy white colour, encircled by very dark orange or red maroon, warts close to aperture confluent, discontinued concentric, denser towards the base of the perigon lobes (Figure 3b), thin solid dark orange and white rings at



Figure 2 The opening flower of *R. zollingeriana* at Tempursari, Lumajang (a), Mt. Lincing, Lumajang (b), Meru Betiri National Park, Jember (c), and Papring, Banyuwangi (d); Papring is the only locality where the flower presented imbricate perigone lobes and a thin solid dark orange and white ring at the edge of the diaphragm; the openness of the diaphragm of Papring specimen is smaller than those of the other three localities

the rim of the diaphragm (Figure 3d). **Windows** absent (Figure 4). **Ramenta** present from the rim of the lower surface of the diaphragm to the base of the perigone tube (Figure 4), tuberculate up to 4 mm, orange, ramenta with various types of its apex at the inner surface of the diaphragm, deeply lobed ramenta at upper to the mid inner surface diaphragm, 4.1 mm high (Figure 4a), swallowed lobes ramenta, 2.5 cm at the mid diaphragm (Figure 4b), branched ramenta, 3.1 mm, simple tubercle ramenta, 2.02 mm in the upper perigone tube (Figure 4c), simple tubercle ramenta on the lower part of the inner surface of the perigone tube (Figure 4d). **Perigone tube** 6.6 cm high (Figure 4pg), 17.74 cm wide at its upper tube, and 12.7 cm wide at its base tube. **Disc** 12.4 cm

to 12.6 cm in diameter (Figure 3e), very light orange, disc rim 9.2–10.56 cm high, very dark orange, and lighter towards the base of the disc (Figure 3g). **Processes** 49, forming 4 rings, from the outer rings towards the centre ring respectively with 20, 17, 8, and 4 processes, truncated-cone shapes with various blunt spikes at its top, light orange at the base, and darker colour towards their apex, the first outer ring, consists of flatty processes 10–11.27 mm high, 13.6 mm wide at its top, 18.44 mm wide at its base, the second outer ring consisting processes 17.70–20.39 mm high, 6.71–7.03 mm wide at its apex, 8.44–12.77 mm at its base, the third ring with processes 15.67–17.99 mm high, 5.3–6.30 mm wide at its apex, and 6.31–6.80 mm at its base, processes at centre 14.8–15.32 mm

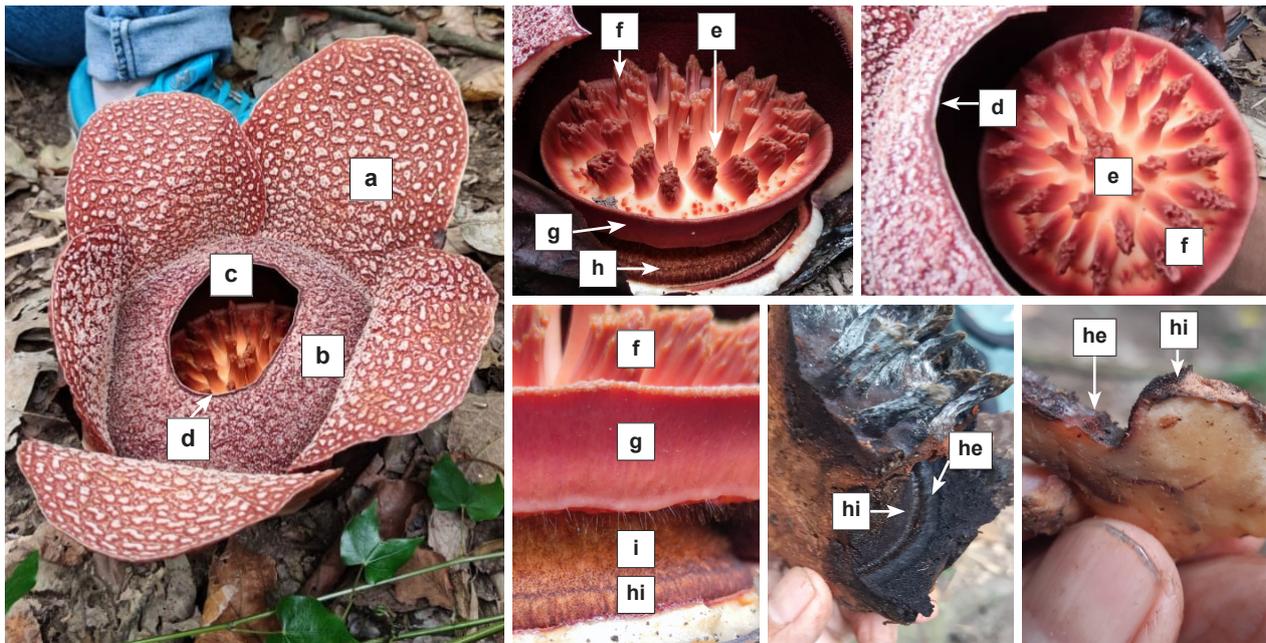


Figure 3 The morphology of the *R. zollingeriana* from Papring; wart pattern, large warts surrounded by small warts at the centre perigone lobe (a), diaphragm (b), diaphragm aperture (c), solid thin dark orange and white rings at the end of diaphragm rim (d), disc (e), processes (f), disc rim (g), annulus (h), interior annulus (hi), exterior annulus (he), column (i); process truncated cone shape with various blunt spikes at its top (f), interior annulus distinctive raised (hi), exterior annulus indistinctively developed (he)

high, 5.80–6.31 mm at its apex, 6.21–6.52 mm at its base (Figure 3f). **Column** 5.02 cm high, 4.7 cm wide at its upper part, 6.3 cm wide at its base, hairy grooves with 2.7–3.4 mm wide running down from the anther sac to the annulus interior (Figure 3i). **Annulus** interior distinctively well-developed, 2.98 mm high, 3.01 mm wide at its base (Figure 3hi), indistinctively developed annulus exterior less than 1.72 mm, 5.4 mm wide at its base (Figure 3he). **Anther** 32, anther cavities with dense hair.

Seven morphological characteristics are generally applied to distinguish taxa within *Rafflesia*, namely, the number of annuli, the structure and distribution of ramenta at the inner surface of the diaphragm and perigone tubes, dimension of the diaphragm, patterns of warts at diaphragm and perigone lobe, windows, the number and structure of processes, and the number of anthers (Beaman et al. 1988, Meijer 1997, Nais 2001, Susatya et al. 2017). All localities showed that the flowering *Rafflesia* and perigone lobes appeared to have almost similar sizes. They respectively ranged from 25 to 35 cm and from 9.3 to 15.6 cm (Table 1). The diaphragm aperture of *Rafflesia* in

Papring was smaller than that of the other three localities (Figure 2, Table 1). It was speculated that the size variation could be related to the microclimates. Colder temperatures, greater air humidity, higher elevations (Susatya 2007), and good soil water availability (Koorders 1918) may lead to the larger size of the opening flower. The size of the opening flowers at all four localities fell into the size range of the opening flower of *R. zollingeriana* recorded by Koorders (1918). According to Koorders (1918), the size is between 15 and 30 cm, and is slightly smaller than that of *R. patma*. Furthermore, Koorders (1918) recognised that size is not of great diagnostic value for taxonomical analysis, due to its tendency to vary among localities.

Wart pattern may easily lead to determining certain *Rafflesia* species. Few and large rectangular warts are distinguishing characteristics for *R. schadenbergiana*, *R. hasseltii* and *R. pricei* (Meijer 1997). *Rafflesia zollingeriana* at all four localities had similar numerous small irregular shape warts on both upper surfaces of the perigone lobes and diaphragm (Figure 2, Table 1). Detailed examination of warts on the perigone lobes revealed two sizes: large warts of 5.3–13.8 mm

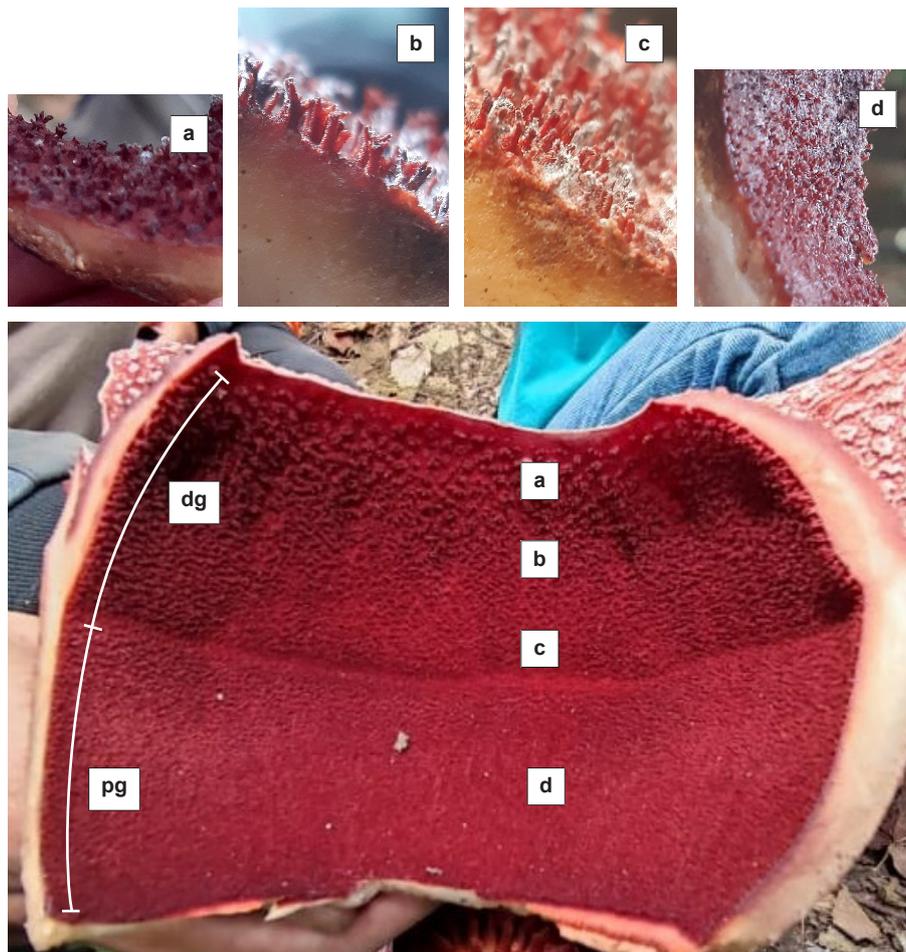


Figure 4 The ramenta structure of *R. zollingeriana* of Papring and its distribution from the inner surface of the diaphragm (dg) through the lower part of the inner surface of the perigone tube (pg). ramenta at the upper (a), mid (b), and lower diaphragm (c), and perigone tube (d)

and small ones with diameters of 2.3–5.3 mm. At the centre of the perigone lobe, warts formed a special pattern, in which the large warts were surrounded by small ones (Figure 3a). Warts at the diaphragm were creamy and encircled by a solid dark orange ring at their rims (Figure 3b). This wart pattern was notably different from the pattern at the perigone lobe. *Rafflesia zollingeriana* of Papring was characterised by the distinct thin dark orange and white rings at its diaphragm rim (Figure 3d). This pattern, along with the wart patterns at both the diaphragm and perigone lobe, was similar to that of *R. arnoldii* and *R. patma* (Susatya 2011). This pattern may also cause the misidentification of *R. zollingeriana* as *R. patma*. This misidentification also occurred with the flowering *Rafflesia* from the island of Sumatera. For example, *Rafflesia* in Sumatera with wart patterns at the perigone lobe similar to *R. arnoldii* was identified as *R. arnoldii*. However, it was later

defined as a new species, *R. lawangensis* (Mat-Salleh et al. 2010), and *R. bengkuluensis* (Susatya et al. 2006).

Tuberculate ramenta was noted in *R. zollingeriana* at Papring and at the other three localities. Tuberculate ramenta with various structures covered the upper part of the inside surface of the diaphragm down to the bottom of the inside surface of the perigone tube. Among Indonesian *Rafflesia*, tuberculate ramenta was found in *R. patma*, *R. zollingeriana*, *R. bengkuluensis*, and presumably the extinct *R. atjehensis* (Meijer 1997, Susatya 2011, Susatya et al. 2017). The ramenta covering the inside surface of the diaphragm and perigone tube of *R. zollingeriana* at all localities indicated that the species had no windows structure (Figure 4). Windows are white blots with mostly circular shapes, various sizes and arrangements, and cover the inside surface of the diaphragm (Beaman et

Table 1 The morphological comparisons among known localities of *Rafflesia zollingeriana* at East Lava Province, Indonesia—Meru Betiri National Park, Jember District, Tempursari and Mt. Lincing from Lumajang District, and Papring from Banyuwangi District

Morphological character	Locality		
	Meru Betiri NP	Tempursari	Mt. Lincing
A. Flowering (cm)	25–27	28–33	26–30
B. Perigone lobe (cm)			
Size (cm)	10–12	12–10	10–11
Number	5	5	5
Colour	Orange	Orange	Orange
Wart	White cream warts in perigone forming regular pattern	White cream warts in perigone forming a regular pattern	White cream blotches in perigone forming regular pattern
C. Diaphragm			
Diameter (cm)	Light orange	Light orange	Light orange
Width (cm)	18–21	15–21	13–14
Aperture	Not observed	Not observed	Not observed
% aperture to the diameter	15–17	8–15	8–9
Wart	80–83	53–71	64–61
Wart	Irregularly white cream	Irregularly white cream	Irregularly white cream
D. Disc			
Diameter	9 cm	9 cm	8 cm
E. Processes, number and size	45; 5–15 mm	37; 2–19 mm	39; 2–12 mm
F. Ramenta			
Ramenta	Tuberculate ramenta at inner diaphragm to perigone tube, lobed ramenta at diaphragm and simple ramenta perigone tube	Tuberculate ramenta at inner diaphragm to perigone tube, lobed ramenta at diaphragm and simple ramenta at perigone tube	Tuberculate ramenta at inner diaphragm to perigone tube, lobed ramenta at diaphragm and simple ramenta at perigone tube
G. Annulus			
Annulus	2, interior annulus less developed than the exterior annulus	2, interior annulus less developed than the exterior annulus	2, interior distinctively well developed, less developed exterior

Meru Betiri NP, Tempursari, Lincing data from Lestari and Susatya (2022)

al. 1988). Meijer (1997) realised the structure of the windows held a considerable taxonomic value for identifying *Rafflesia*, and further provided diagrammatic pictures of the different windows for three different species. Species with no windows are not uncommon in *Rafflesia*. The species with the absence of windows include *R. patma* (Meijer 1997), *R. zollingeriana* (Koorders 1918, Meijer 1997), *R. tengku-adlinii* (Mat-Salleh & Latiff 1989), *R. lawangensis* (Mat-Salleh et al. 2010), *R. baleteti*, *R. leonardi*, *R. mira*, and *R. schadenbergiana* (Barcelona et al. 2009).

In searching for good morphological characters for identifying *Rafflesia* species and after examining the article by Winkler (1927), Meijer (1997) conclude that the ramenta provide great diagnostic value due to the consistency of its structure. He further provided a diagrammatic picture of the different ramenta structures for 11 different species (Meijer 1997). Meijer later grouped the species of *Rafflesia* into *R. arnoldii*, *R. patma*, and *R. hasseltii* complexes (Susatya 2011, Susatya et al. 2017). The member of each complex was characterised by both similar ramenta structure and physical appearance. Meijer's idea on species complexity was further developed by Susatya et al. (2017) by adding a new complex, *R. pricei*.

Rafflesia species generally have two interior and exterior annuli. The annulus is a raised ring-shaped structure at the bottom of the central column of the *Rafflesia*. Meijer (1997) separated and grouped the species of *Rafflesia* according to the number of annulus. The importance of the annulus structure for the taxonomy of *Rafflesia* was earlier recognised by Koorders (1918). Koorders developed the early key determination of all *Rafflesia* by using the number of the annulus as the first step to identify *Rafflesia*. According to Koorders, species that have two distinctive annuli consists of *R. arnoldii*, *R. patma*, *R. borneensis*, *R. witkampii*, *R. ciliata* and *R. tuan-mudae*. Another group species was characterised by a single raised inner ring at the base of the column or interior annulus and a flat or barely elevated exterior annulus. This group consists of *R. zollingeriana*, *R. cantleyi*, *R. manillana*, *R. hasseltii*, *R. scanderbergiana* and *R. rochussenii*. The morphological comparisons regarding the annulus structure from specimens collected from all four localities showed an interesting pattern. All localities showed two

annuli with one well-developed or distinctive, and the other less developed. *Rafflesia* from Papring showed a distinctive interior annulus, but a less developed exterior annulus (Figures 3he, Figure 3hi). This pattern was opposite to that of the other three localities. *Rafflesia zollingeriana* from the other three locations showed a less developed interior, but distinctive exterior annuli (Table 1). This becomes an interesting finding. In the early manuscript by Koorders (1918), *R. zollingeriana* was characterised by a single distinctive interior annulus with an almost flat or absent exterior annulus. The description by Koorders matches the description of the *R. zollingeriana* in Papring. This further raises questions about whether the distinctiveness of the annulus structure can vary according to the geographical range and environment, or whether speciation is taking place in the other three localities.

The geographical range of plants is important not only for ecology but also for the conservation and survival of the species (Ancheta 2021). Papring is regarded as the easternmost of the geographical range of *R. zollingeriana* in Java. The occurrence of this species was also likely noted by Zollinger during his journey to the northern Banyuwangi (Koorders 1918). The site is covered by a dry secondary forest with bamboo sprouts and mixed pine–teak trees as the dominant vegetation. The other three localities are similarly covered by secondary forest vegetation. All four localities are fragmented forests and isolated from each other.

Banyuwangi landuse has drastically changed over the last 20 years. Within this period, its secondary forest has decreased by 40% (Wahyuni et al. 2021). Fragmentation has affected many *Rafflesia* species (Meijer & Elliott 1990, Barcelona et al. 2009, Susatya 2011). Conserving these fragmented localities and populations becomes more important for the survival of the species. Furthermore, Kusuma et al. (2022) recognise that *R. zollingeriana* is one of three Javan *Rafflesia* that has low genetic diversity. Therefore, any new local population is important in terms of the genetic diversity of the species. Barkman et al. (2017) also suggested that loss of each local population will generate a large genetic loss and reduce the survival of future species.

As with Papring, the other three localities also experience variations in the number of wet and dry months. Meru Betiri. Lincing and

Tempursari localities receive 2013, 2345 and 2252 mm annual rainfall respectively. All localities are characterised by distinct dry and rainy seasons. As all localities are relatively close to the ocean, their climatic regime may be influenced by the oceanic climate. Interestingly, all Indonesian *Rafflesia* with tuberculate ramenta consisting of *R. patma*, *R. zollingeriana* and *R. bengkulensis* occupy habitats near the ocean (Susatya et al. 2017). It raises speculation whether these unique climate patterns may determine the size of opening *Rafflesia* as well as the presence of tuberculate ramenta on the species.

Twenty-five populations of Papring were found at different sites from 371 to 426 m asl with moderate to heavy terrains from 25 to 52% slope. The locations are quite distant from any rivers. The closest stream or creek is 70 m away and dry during the dry season. The steep slope is typical of most of the habitat terrain in all localities of *R. zollingeriana* (Hikmat 2006, Lestari et al. 2014), *R. baletei*, *R. philippensis* (Barcelona et al. 2009), *R. arnoldii*, *R. gadutensis* (Susatya 2011, Pranata et al. 2019), *R. lawangensis* (Mat-Salleh et al. 2010), and *R. kemumu* (Susatya et al. 2017). Land slope is one of the factors that determine the distribution and growth of *Rafflesia* (Beaman et al. 1988). Other factors, e.g. rainfall, humidity, temperature, light intensity, and edaphic factors such as pH and soil nutrients influence the geographical distribution of the species (Jiang et al. 2017).

Attempts to develop models to determine geographical distribution or suitable habitat for *Rafflesia* had been carried out by Ancheta (2021) for *R. schadenbergiana* and *R. consueloae* and by Renjana et al. (2022) for *R. arnoldii*. Both authors used elevation, temperature, rainfall and land cover type to develop the models. Renjana et al. (2022) also included the geographical distribution of three species of *Tetrastigma* in the model. The optimal growth of *R. schadenbergiana* lies in areas with elevations between 640 and 1400 m asl where the temperature reaches 20–22 °C, and annual rainfall is between 1993 and 2350 mm. Optimal growth of *R. consueloae* is between 200 and 500 m asl, where the temperature reaches 24–25 °C, and annual rainfall is 1993–2380 mm (Ancheta 2021). Using GIS-based habitat modelling, *R. arnoldii* was found in the western parts of Bukit Barisan Mountains in Sumatra (Renjana et al. (2022). The authors conclude that *R. arnoldii* occupy habitats from 35 to 1024 m asl

with temperatures between 25 and 29 °C. They also infer that the most influential environmental factors for the geographical distribution of *R. arnoldii* are temperature, slope and elevation. The temperature, elevation and annual rainfall of the Papring locality are similar to that of *R. arnoldii*.

Among the striking features of the biophysics of the habitat of *Rafflesia* are the slope of the terrain and the proximity of its locations to rivers. For example, *R. kerrii* was recorded on a steep slope and near a river (Kedri et al. 2018). This is also true for the sites of *R. arnoldii* (Susatya 2011, Pranata et al. 2019), *R. bengkulensis* (Susatya et al. 2006), *R. philippensis*, *R. schadenbergiana*, and *R. mira* (Barcelona et al. 2009). It is assumed that the availability of water resources from the rivers determined the growth and distribution of the species (Nais & Wilcock 1998). Another interesting habitat feature is the condition of forest cover or forest ecosystems. *Rafflesia arnoldii*, *R. bengkulensis*, and *R. kemumu* are more frequently reported flowering on private lands, forest margins, and young secondary forests, rather than in old-growth forests (Susatya 2011). These similar habitat types are also shared by *R. baletei*, *R. lobata*, *R. manillana*, *R. mira*, *R. philippensis*, *R. schadenbergiana* and *R. speciosa* (Barcelona et al. 2009). This habitat feature was similarly found at all localities of *R. zollingeriana*, where the land cover was relatively open and consisted of degraded forests.

Rafflesia is an endophytic and holoparasitic plant hosting on *Tetrastigma*. The geographical range of *Rafflesia* is indeed the distribution of the *Rafflesia*-infected *Tetrastigma*. Any observation on the distribution range of *Rafflesia* should cover the habitat requirements of *Tetrastigma*. *Tetrastigma* is known as a woody liana, and its geographical range and abundance depend on forest structure, tree architecture (Putz 1984, 1985), and forest disturbance (Richard 1952). Woody liana is generally found in forests experiencing disturbances such as forest gaps (Richard 1952), forest edge, and riparian (William-Linera 1990). Riparian or habitat near rivers or streams can be considered as dynamic land that continually changes over time due to natural disturbances (eg. falling trees). Any disturbed habitat, steep slope or ridge, tree fall area, or forest gap becomes suitable habitat for *Tetrastigma*.

CONCLUSION

A newly recorded *R. zollingeriana* at Papring, Northeastern Banyuwangi, East Java extended the geographical range, added to the number of known local populations, and enriched the morphological as well as genetic diversity of the species. Flowering *R. zollingeriana* of Papring was slightly morphologically different to those in Meru Betiri National Park, Tempursari, and Lincing. The *R. zollingeriana* in Papring displayed a smaller flowering bud and diaphragm aperture, and solid dark orange and white ring at the rim of the diaphragm. They also displayed a dark orange to red maroon colour in their perigone lobes and diaphragm, while *R. zollingeriana* from the other three localities were orange in colour. *Rafflesia zollingeriana* of Papring differs from *Rafflesia* in the other three localities in regard to their annulus structure, whereby the flower in Papring shows a distinctive interior and less developed or indistinctive exterior annuli, while in the other three localities, the flower has less developed interior, but distinctive exterior annuli. *Rafflesia zollingeriana* at all localities shows no windows with tuberculate rammenta covering the inner surface of the diaphragm and perigone tube. The geographical range of the species is fragmented and exists in habitats isolated from each other. It occupies disturbed secondary forests at 371–426 m asl with moderate to steep slopes. The range also experiences monsoon climates with distinct dry and rainy seasons. The geographical range of the species follows the distribution of infected *T. rafflesiae*, *T. dichotomum* and *T. papillosum*.

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REFERENCES

- ANCHETA MH. 2021. Distribution modeling of *Rafflesia schadenbergiana* and *Rafflesia consueloae* using multi-criteria decision analysis-analytical hierarchy process in GIS. *Journal of Degraded and Mining Lands Management* 8: 2903–2909. <https://doi.org/10.15243/jdmlm.2021.084.2903>
- BARCELONA JL, PELSER PB, BELETE DS & CO LL. 2009. Taxonomy, ecology, and conservation status of Philippine *Rafflesia* (Rafflesiaceae). *Blumea* 54: 77–93. <https://doi.org/10.3767/000651909X474122>
- BARKMAN TJ, KLOOSTER MR, GADDIS KD ET AL. 2017. Reading the vines: hosts as islands for extreme holoparasitic plants. *American Journal of Botany* 104: 1382–1389. <https://doi.org/10.3732/ajb.1700117>
- BEAMAN RS, DECKER PJ & BEAMAN JH. 1988. Pollination of *Rafflesia* (Rafflesiaceae). *American Journal of Botany* 75: 1148–1162. <https://doi.org/10.1002/j.1537-2197.1988.tb08828.x>
- EMMONS LH, NAIJ J & BRIUN A. 1991. The fruit and consumers of *Rafflesia keithii* (Rafflesiaceae). *Biotropica* 23: 197–199. <http://dx.doi.org/10.2307/2388307>
- HIKMAT A. 2006. Kecenderungan populasi *Rafflesia zollingeriana* Kds. di Taman Nasional Meru Betiri, Jawa Timur. *Media Konservasi* 11: 105–108.
- JIANG C, TAN K & REN MX. 2017. Effects of monsoon on distribution patterns of tropical plants in Asia. *Chinese Journal of Plant Ecology* 41: 1103–1112. <https://doi.org/10.17521/cjpe.2017.0070>
- KEDRI FK, HAMZAH Z, SUKRI NS ET AL. 2018. Distribution and ecology of *Rafflesia* in Royal Belum State Park, Perak, Malaysia. *International Journal of Engineering & Technology* 7 (Special Issue 29): 292–296. <https://doi.org/10.14419/ijet.v7i2.29.13335>
- KOORDERS SH. 1918. *Botanisch Overzicht der Rafflesiaceae van Nederlandsch-Indië*. G. Kloff & Co., Batavia.
- KUSUMA YWC, NOERWANA O & ISAGI Y. 2018. New evidence for flower predation on three parasitic *Rafflesia* species from Java. *Tropical Conservation Science* 11: 1–6. <https://doi.org/10.1177/1940082918796011>
- KUSUMA YWC, MATSUI A, SUYAMA Y, WANKE S & ISAGI Y. 2022. Conservation genetics of three *Rafflesia* species in Java Island, Indonesia using SNP markers obtained MIG-seq. *Conservation Genetics* 23: 1039–1052. <https://doi.org/10.1007/s10592-022-01470-6>
- LAKSANA I, SYARIFUDDIN A & ARYANTI NM. 2018. Habitat *Rafflesia* (*Rafflesia zollingeriana* Kds.) di blok Krecek Resort Bandelalit Taman Nasional Meru Betiri, Jawa Timur. *Journal of Forest Science Avicennia* 1: 30–39. <https://doi.org/10.22219/avicennia.v.1i2.5598>
- LESTARI D, HIKMAT A & ZUHUD EAM. 2014. Distribusi baru dan struktur populasi *Rafflesia zollingeriana* Koord. di Taman Nasional Meru Betiri, Jawa Timur. *Bulletin Kebun Raya* 17: 69–79.

- LESTARI D & MAHYUNI R. 2021. *Rafflesia zollingeriana* Koord: a reinstatement. *Jurnal Biodjati* 6: 213–221.
- LESTARI D & SUSATYA A. 2022. Morphological variation of *Rafflesia zollingeriana* Koord. and its recent distribution in East Java, Indonesia. *Biosaintifika* 14: 117–124. <https://doi.org/10.15294/biosaintifika.v14i1.33089>
- MAEZULPAH, BRILIAWAN BD, FAIRUZ R ET AL. 2019. Population structure and conservation strategy of *Rafflesia zollingeriana* Koord. in Bandalit Resort, Meru Betiri National Park. *ICTS IOP Conference. Series: Earth and Environmental Science* 394: 1–8. <https://doi.org/10.1088/1755-1315/394/1/012008>
- MASDUKI A, SUBCHAN W & PRIHATIN J. 2019. *Serangga Pengunjung Rafflesia zollingeriana K. di Taman Nasional Meru Betiri*. LaksBang Pressindo, Yogyakarta.
- MAT-SALLEH K & LATIFF A. 1989. A new species of *Rafflesia* and other species from Trus Madi Range, Sabah (Borneo). *Blumea* 34: 111–116.
- MAT-SALLEH K, MAHYUNI R, SUSATYA A & VELDKAMP JF. 2010. *Rafflesia lawangensis* (Rafflesiaceae) a new species from Bukit Lawang, Gunung Leuser National Park, North Sumatra, Indonesia. *Reinwardtia* 13: 159–165. <http://dx.doi.org/10.55981/reinwardtia.2010.2136>
- MEIJER W. 1997. Rafflesiaceae. *Flora Malesiana, Series 1*. 13: 1–42.
- MEIJER & ELLIOTT S. 1990. Taxonomy, ecology, and conservation of *R. kerrii* Meijer in Southern Thailand. *Natural History Bulletin of the Siam Society* 38: 117–133.
- NAIS J & WILCOCK CC. 1998. The *Rafflesia* conservation incentive scheme in Sabah, Malaysia, Borneo. *Sabah Parks Nature Journal* 1: 9–17.
- NAIS J. 2001. *Rafflesia of the World*. Sabah Parks, Kota Kinabalu.
- NURYADI & AGUSTIARINI S. 2018. Analisis kerawanan kekeringan lahan padi Kabupaten Banyuwangi Jawa Timur. *Jurnal Meteorologi Klimatologi dan Geofisika* 5: 29–36. <https://doi.org/10.36754/jmkg.v5i2.56>
- PRANATA S, SULISTIJORINI C & CHIKMAWATI T. 2019. Ecology of *Rafflesia arnoldii* (Rafflesiaceae) in Pandam Gadang West Sumatra. *Journal of Tropical Life Science* 9: 243–251. <https://doi.org/10.11594/jtls.09.03.05>
- PUTZ FE. 1984. The natural history of liana on Barro Colorado Island. *Ecology* 65: 1713–1725.
- PUTZ FE. 1985. Woody vines and forest management in Malaysia. *Commonwealth Forestry Review* 64: 359–365.
- RENJANA E, ASTUTI IP, MUNAWAROH E ET AL. 2022. Assessing potential habitat suitability of parasitic plant: a case study of *Rafflesia arnoldii* and its host plants. *Global Ecology and Conservation* 34: e02063. <http://dx.doi.org/10.1016/j.gecco.2022.e02063>
- RICHARD PW. 1952. *The Tropical Rain Forest*. Cambridge University Press, Cambridge.
- SANDI ES, SURYANI E, GHULAM M & ERWANTO Z. 2011. *Analisis Tingkat Kekritisitas DAS Bajulmati dengan Menggunakan Sistem Informasi Geografis*. Laporan Penelitian Politeknik Banyuwangi, Banyuwangi.
- SITI-MUNIRAH MY, SALAMAH A & RAZELAN MS. 2020. On the morphological variation of *Rafflesia cantleyi* (Rafflesiaceae) on Pulau Tioman, Pahang, Peninsular. *Blumea* 65: 75–82. <https://doi.org/10.3767/blumea.2020.65.01.09>
- SUSATYA A, ARIANTO W & MAT-SALLEH K. 2006. *Rafflesia bengkulensis* (Rafflesiaceae) a new species from South Sumatra, Indonesia. *Folia Malaysiana* 6: 139–152.
- SUSATYA A. 2007. Taxonomy and ecology of *Rafflesia* in Bengkulu, Indonesia. PhD thesis, Universiti Kebangsaan Malaysia, Bangi.
- SUSATYA A. 2011. *Rafflesia—Pesona Bunga Terbesar di Dunia*. Direktorat Kawasan Konservasi dan Bina Hutan Lindung, Jakarta.
- SUSATYA A, HIDAYATI SN, MAT-SALLEH K & MAHYUNI R. 2017. Ramenta morphology and its variations in *Rafflesia* (Rafflesiaceae). *Flora* 230: 39–46. <https://doi.org/10.1016/j.flora.2017.03.001>
- WAHYUNI NI, HASYIM AW & SOEMARNO. 2021. Dinamika perubahan dan tutupan lahan di Kabupaten Banyuwangi periode 1995–2019. *Jurnal Wasian* 8: 121–132. <https://doi.org/10.20886/jwas.v8i2.6707>
- WILLIAM-LINERA G. 1990. Vegetation structure and environmental conditions of forest edges in Panama. *Journal of Ecology* 78: 356–373.
- WINKLER H. 1927. Über eine *Rafflesia* aus zentralBorneo. *Planta* 4: 1–97. <https://doi.org/10.1007/BF01911186>
- ZUHUD AM, HIKMAT A & JAMIL N. 1998. *Rafflesia Indonesia: Keanekaragaman, Ekologi dan Pelestariannya*. Yayasan Pembina Suaka Alam, Suaka Margasatwa Indonesia and Institut Pertanian Bogor, Bogor.