

Rethinking rumbia palm (*Metroxylon sagu* Rottb.) cultivation as a nature-based solution for peatland restoration and biodiversity enhancement in South Sumatra, Indonesia

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Received: 06 October 2025 / Accepted: 16 January 2026 / Available online: 26 January 2026



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Abstract

Peatlands in South Sumatra are increasingly degraded due to anthropogenic activities and climate change. Effective restoration therefore requires broad consensus on conserving biodiversity and carbon stocks through the planting of native peat species, such as rumbia palm (*Metroxylon sagu* Rottb.). This study aimed to evaluate the suitability of peatlands for rumbia palm cultivation and to identify the main limiting factors affecting its development. The research combined field observations, laboratory analyses, and environmental assessments to evaluate the physical and chemical characteristics of local peatlands. Results indicated that rumbia palm is closely linked to the cultural history of the Sriwijaya Kingdom in Palembang, yet has become marginalised due to widespread conversion of peatlands into industrial plantations. Soil acidity, nutrient levels, and peat depth were found to be the primary limiting factors influencing cultivation potential. Overall, the study shows that peatlands in South Sumatra have high potential for rumbia palm cultivation under proper management practices, such as soil improvement, fertilisation, and groundwater regulation. The novelty of this research lies in positioning rumbia palm cultivation as an indigenous, biodiversity-supporting, nature-based solution for restoring ecological functions of tropical peatlands.

Key words: degraded peatlands, peatland restoration, soil ameliorant, sustainable restoration.

Introduction

Preventing peatland conversion is very difficult because the government has prepared peatland plans for industrial plantations, agriculture, and non-agricultural uses (Armanto et al. 2025a). All peatland reclamation requires drainage and exces-

sive drainage leads to peatland subsidence, irreversible drying, gas emissions, biodiversity loss, and devastating peat fires. The stability is strongly influenced by its water content (Yamamoto et al. 2020). Peatlands should ideally be highly moist to allow consistent, long-term peat accumulation that can be restored. Sus-

tainable peatland management has to be a top priority to slow climate change and promote green economic growth (Arman-to 2019a,b). Fires and carbon emissions are two environmental impacts of agricultural methods using canals to drain peatlands. They have to be managed sustainably due to their fragile ecosystems.

Rewetting, revegetation, and livelihood revitalisation (3R programs) are programmes for peatland restoration. Rewetting degraded peatlands reduces net greenhouse gas emissions significantly. Replanting with peat native plants that were once present there is known as paludiculture (Byg et al. 2023) with three methods, namely maximum replanting, enrichment, and natural succession. One way to compensate communities surrounding peatland restoration is to revitalize the livelihoods of indigenous communities. Three categories of their livelihood revitalisation programmes are known as: ecosystem service-based, land-based, and water-based. Carbon trading belongs to ecosystem service-based program, paludiculture is typically thought of as a land-based agricultural method used on peatlands, and fisheries can be categorised as water-based restoration (BRGM 2022).

Rumbia palm (*Metroxylon sagu* Rottb., syn. *M. rumphii* Mart.) cultivation study on peatlands is still limited and only identified the results of its cultivation with certain treatments without considering land suitability criteria. For a wide variety of wild plants and animals, rumbia palm (as a native peat species) offers a stable, nutrient-rich habitat, making it a foundation species that is crucial to carbon sequestration (Bagasbas and Barroca 2020). Its cultivation and peatland restoration can conserve biodiversity and carbon storage while also fostering a strong local econo-

my (Dimara et al. 2021). Although it grows in flooded conditions, production is better if the peatland can fluctuate between flooded and dry conditions (Sasaki et al. 2025). Canals with barriers are necessary to maintain water level stability in peatlands and serve as transportation routes for harvested rumbia palm trunks (Syakina et al. 2024a,b). This study aimed to evaluate the suitability of peatlands for rumbia palm cultivation and to identify the main limiting factors affecting its development. The findings are expected to inform land-use planning for the cultivation of rumbia palm within peatland restoration efforts.

Materials and Methods

Study plots

The study plots are peatland areas located in the eastern part of South Sumatra Province, situated at an elevation of 0–5 m a.s.l., and relatively isolated, although they are accessible via numerous rivers (Fig. 1). Plot 1, with a peat depth of 50–100 cm, is located at 104°57'18.58" E and 3°26'37.31" S; Plot 2 (100–200 cm) is situated at 104°53'35.12" E and 3°25'53.37" S; Plot 3 (200–300 cm) is positioned at 104°57'52.38" E and 3°25'22.34" S; and Plot 4 (>300 cm) is located at 104°57'54.55" E and 3°25'20.43" S.

Study methods

Purposive and composite soil sampling was conducted from four observation plots. A three-quadrant transect approach was employed as the data gathering technique with each plot measuring 10×10 m for tree observation, 5×5 m for sapling observation, and 2×2 m for seedling observation. Next, the peat samples were dried

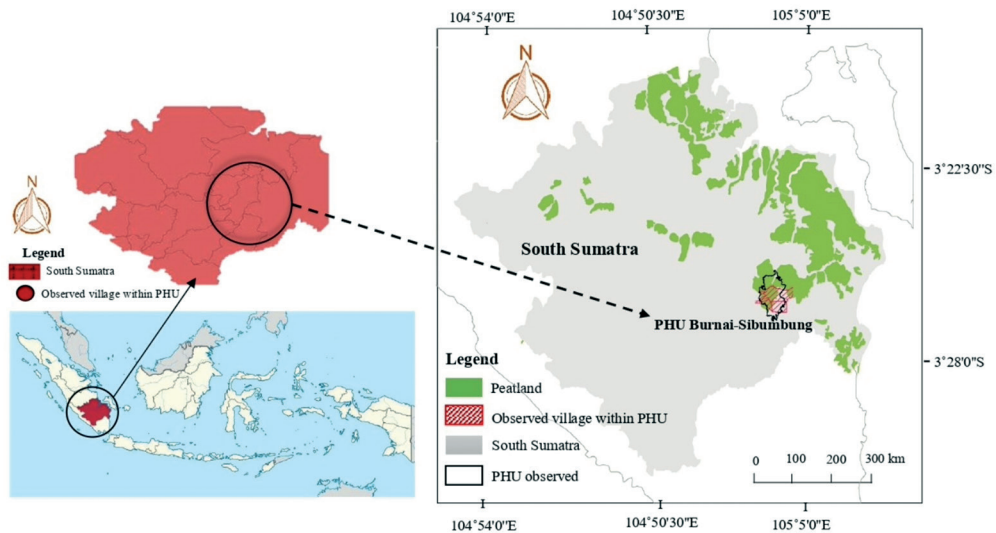


Fig. 1. Distribution of dominant peatlands in South Sumatra, Indonesia and study plots.

and analysed in the laboratory. Study parameters and their measurement techniques are summarised in Table 1 (ASTM International 2025).

Table 1. Study variables and their measuring techniques.

Parameter and units	Methods
Water content, %	Oven-drying and weighing
Bulk density, $\text{g}\cdot\text{cm}^{-3}$	Core (ring) samples and weighing
Total pore space, %	Derived from bulk density and particle density
Organic C, %	Walkley and Black method
Total N, %	Wet digestion with H_2SO_4 , spectrophotometric determination
C/N ratio	Calculated ratio
Peat depths, cm	Boring method
Soil acidity, pH value	pH meter
Inundation depth, cm	Piezometer reading
Moisture content (wet), %	Air-drying and weighing
Moisture content (dry), %	Oven-drying and weighing
Groundwater level, cm	Field measurement
Fiber content, %	Sieving and weighing
Ash content, %	High-temperature and laboratory analyses
Dry biomass, $\text{kg}\cdot\text{ha}^{-1}$	Weighing and oven-drying
Total biomass, $\text{kg}\cdot\text{ha}^{-1}$	Calculated as $1.74 \times \text{organic C, \%}$
Available P, K, $\text{kg}\cdot\text{ha}^{-1}$	Wet digestion with HNO_3 and H_2SO_4 , spectrophotometric determination

Note: Organic carbon (C), total nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulphuric acid (H_2SO_4), and nitric acid (HNO_3).

Method for determining rumbia palm suitability was carried out according to Ministry of Agriculture Regulation (2021), No 79/Permentan/OT.140/8/2013. Land suitability was assessed using the matching method, namely by matching peatland parameters with rumbia palm growth requirements (Armanto et al. 2013).

Results and Discussions

Rumbia palm ethnobotany and decline in the South Sumatra peatlands

The ethnobotany of rumbia palm was an important aspect of daily life among the Sriwijaya communities, which were located in the southern part of Sumatra, particularly around Palembang City and the Musi River in South Sumatra, Indonesia. The relationship between rumbia palm and the Sriwijaya Kingdom was directly documented in the main historical inscription stone of the Sriwijaya Kingdom. Based on ethnobotanical, geographical and archaeological studies, several pieces of information can be drawn (Table 2). Sriwijaya kingdom may have traded rumbia palm with other kingdoms, given its role in extensive maritime trade and rumbia palm contributed to the survival of the

Sriwijaya community and had an impact on the local economy at that time. These findings are consistent with those of other researchers (Wildayana et al. 2018).

Rumbia palm trunks are harvested to produce rumbia palm starch. The carbon cycle, ecological functions, and wildlife species dependent on rumbia palms are all negatively impacted by deforestation. Biodiversity, carbon storage protection, and regional economic stability can be maintained by combining rumbia palm cultivation with sustainable peatland restoration.

The condition in South Sumatra is very ironic, rumbia palm has become almost extinct in the peatlands due to several interrelated factors. The main drivers of its decline are predominantly anthropogenic (79 %), including land conversion and drainage, while natural factors such as fire and climate account for only 21 %. This is relevant to the findings reported by Wildayana and Armanto (2018). It means that if peatlands were not influenced by humans, it was very possible that rumbia palm would still be found. Here are some of the main reasons why rumbia palm is difficult to find in the study plots today:

1) Land conversion for industrial plantations (53 %). This activity causes major changes in the ecosystem and the loss of

Table 2. Information about sago written on the stone inscriptions of the Sriwijaya kingdom.

Uses of rumbia palm	General descriptions
Food source	In coastal and swamp areas, sago was the main source of carbohydrates, especially for indigenous communities.
Food trade and distribution	Sriwijaya was a maritime kingdom and a centre of international trade. In its logistics system, indigenous foodstuffs such as sago, coconut, and dried fish were essential as provisions for sea travel and daily consumption. Sago is known to last a long time after being processed into flour, making it suitable as a logistical reserve food.
Non-food uses	Building materials (leaves and stems). Animal feed and by-products (sago worms as a source of protein).

Source: Field survey and literature review (2025).

natural habitat for rumbia palm. Peatlands that used to be fertile places for it to grow are now being converted into plants that are more economically profitable.

2) Peatland drainage for agriculture and industrial plantations caused a decrease in water content in the soils playing a role of around 26 %. Rumbia palm requires waterlogged environment to grow well. If peatlands are drained, they are no longer ideal for planting rumbia palm.

3) Frequent land fires. They will damage the peat ecosystem including rumbia palm because fires reduce its number. Rumbia palm belongs to a fire-resistant species, therefore the role of fire in the destruction is relatively small (only 12 %).

4) Climate change affects the peat ecosystem and the growth of rumbia palm (playing a role of 9 %). Extreme weather conditions (such as longer droughts or erratic rainfall) can damage the peat ecosystem supporting rumbia palm growth.

Rumbia palm is often less considered in agricultural policies and natural resource management, so its existence is increasingly threatened. Overall, its loss in peatlands is caused by a combination of human activities, environmental damage, and climate change. Preserving rumbia

palm requires a more holistic approach, including better peatland management and protection of existing ecosystems.

South Sumatra is forced to import rumbia palm flour from outside to meet the need for pempek (a typical South Sumatran food) made from rumbia palm flour, on the other hand, many peatlands are abandoned and degraded. It would be a useful if these peatlands can be utilised for rumbia palm cultivation. Besides making pempek, rumbia palm can be processed into a variety of foods (noodles, cakes, etc.). The protein, glucose, and dextrin content in it can be utilised in the food and beverage, pharmaceutical, paper, wood, cosmetics, and pesticide industries. Its production waste is used as fertilizer, animal feed, or as fuel briquettes. Among the several immediate advantages of rumbia palm are its starch, fibre, leaves, leaf stalks, larvae, sap, palm kernel, seeds, and roots. It became a staple, generating flour other than tapioca, protecting the environment, and reducing reliance on imports. Rumbia palm trunks have to be incorporated into social forestry and peat restoration projects in order to restore rumbia palm food security and strengthen environmental-based food security (Fig. 2).



Rumbia palm trees



Rumbia palm processing



Rumbia palm flour

Fig. 2. Rumbia palm (*Metroxylon sagu*) as a potential species for peatland rehabilitation and local food production.

Key variables of rumbia palm suitability in peatlands

The climate conditions for all study areas meet the criteria of highly suitable (S1) and ideal for rumbia palm growth. The average air temperature, according to climate data from 2000 to 2024, is 31 °C. The region is categorised as S1 (highly suitable) because of its average annual rainfall of 3,128 mm.

The peat depth determines the adaptability of rumbia palm growth. Its growth is slightly inhibited in deep peatland because rumbia palm roots cannot penetrate the deep peatland substrate layer, which often consists of nutrient-rich sediment layers. If the peatland is shallow, the substrate layer below the peatland layer provides sufficient nutrients and can be absorbed by its root system. In other words, it can be said that the deeper the peatland, the worse the environment is to support rumbia palm growth (Table 3).

For all study plots, the lowest bulk density (BD) was often found in the deepest peat layers, increasing with decreasing depth and reaching a maximum in the shallower layers (50–100 cm). This pattern is due to the greater influence of human activities and river systems on shallow peat compared with deeper layers. These activities include industrial plantations, illegal logging, agriculture, slash-and-burn farming, grazing, and fisheries. The peatland surface, which experiences high temperatures burning charcoal production through pyrolysis process, is the primary site of fires and other disturbances.

Changes in peat properties generally occur in the shallower layers, particularly where BD increased; organic carbon (C) decreases, while ash and fibre content are reduced. At these depths, peat particles are more vulnerable to water flow, fire, and extreme heat. Fine peat particles can be transported by water to fill holes, crevices,

Table 3. Average key variables of peatland suitability and Tukey HSD test.

Key variables	Peatland depth, cm			
	50–100	100–200	200–300	>300
BD, g·cm ⁻³	0.23 ^a	0.23 ^a	0.14 ^b	0.15 ^b
TPS, %	82 ^a	84 ^a	88 ^b	88 ^b
Organic C, %	41.96 ^a	43.50 ^{ab}	49.11 ^c	48.73 ^c
Total N, %	1.79 ^a	1.78 ^a	1.99 ^a	1.95 ^a
C/N ratio	23.44 ^a	24.44 ^a	24.68 ^a	24.99 ^a
P ₂ O ₅ , kg·ha ⁻¹	3.29 ^a	3.20 ^a	3.15 ^a	3.10 ^a
K ₂ O, kg·ha ⁻¹	11.08 ^a	11.02 ^a	9.97 ^a	9.21 ^a
WM, %	443 ^a	468 ^b	470 ^b	472 ^b
DM, %	80 ^a	84 ^a	80 ^a	84 ^a
GWT, cm	41 ^a	39 ^a	20 ^b	21 ^b
Fiber, %	23.34 ^a	24.40 ^a	37.02 ^c	30.50 ^b
Ash, %	5.36 ^a	5.42 ^a	5.89 ^a	10.12 ^b

Note: Bulk density (BD), total pore space (TPS), organic carbon (C), total nitrogen (N), wet moisture (WM), dry moisture (DM), and groundwater table (GWT). Mean values with the same superscript in each row indicate no significant difference at *p* < 0.05 based on Tukey HSD test. Source: Results of laboratory data analysis (2025).

and fissures on the peat surface, affecting several peat characteristics. Total pore space (TPS) and BD exhibit an inverse relationship: higher TPS corresponds to lower BD. Shallow peatlands exhibited the lowest TPS values (82–84 %), whereas deeper peatlands had the highest TPS values (88 %). Consequently, a decrease in TPS is associated with an increase in BD, indicating peat compaction.

Organic C, N, and the C/N ratio exhibited the following patterns: shallow peat (41.96–43.50 %) contained considerably lower organic C compared with deep peat (48.73–49.11 %). Although N values showed no significance overall variation, shallow peatlands experienced greater N losses due to more extensive decomposition. The C/N ratio did not vary markedly across all sampling plots; however, peatlands appear increasingly degraded, as evidenced by a declining ratio.

Several studies on ombrotrophic peatlands have also reported that the C/N ratio increases with depth. In addition to N losses through volatilisation during peat burning, repeated fires deplete soil biomass, further reducing overall N concentrations. Consequently, deep peatlands were found to have a higher C/N ratio. Land clearing was the primary factor driving the decline in N concentrations in shallow peatlands. Maintaining crop residues *in situ* can help preserve a higher C/N ratio, while available P and available K do not show significant differences with peat depth.

Limiting factors of rumbia palm suitability in peatlands

Rumbia palm is highly suitable for growth on peatlands, but several factors must be considered to ensure these ecosystems remain suitable for supporting its development. In general, peatlands possess

characteristics favourable to rumbia palm growth; however, proper management is crucial. Similar findings have been reported by other researchers (Armanto et al. 2025b,c). The main factors are summarised below.

1) Moisture conditions

Rumbia palm requires peatlands that remain constantly moist and waterlogged. Peatlands naturally maintain high humidity because of their ability to store large volumes of water. Therefore, consistently moist peatlands are ideal.

2) Soil acidity (pH)

Peatlands generally have low pH values varying between 3.5 and 5.5. Rumbia palm can tolerate acidic soil, although excessively low pH can inhibit root growth. The optimal pH range is between 4.0 and 6.0.

3) Nutrient availability

Peatlands are often deficient in essential nutrients such as nitrogen (N), phosphorus (P), and potassium (K). Therefore, additional fertilisation is required to ensure optimal growth and productivity.

4) Peat depth

Rumbia palm grows best in shallow peat, where the root system can reach the underlying mineral substrate that serves as an anchor and nutrient source. In deep peat, the roots cannot reach this layer, making the plant more prone to waterlogging and poor stability.

5) Drainage and hydrology

Peatland drainage disrupts the hydrological balance and is detrimental to rumbia palm cultivation. Excessive drainage leads to peat degradation, drying, and increased fire risk. Proper water management is therefore essential.

6) Groundwater level

Rumbia palm grows best where groundwater levels are maintained between 20–30 cm below the peat surface. Both overly

deep and overly shallow water tables can stress the plants and reduce yield.

7) Sustainable management

Wise management practices are crucial for maintaining peatland suitability. This includes preventing its conversion for industrial plantations, avoiding burning, and maintaining appropriate soil moisture to support healthy rumbia palm growth.

8) Climate change impacts

Climate change can affect the suitability of peatlands for rumbia palm. Changes in rainfall patterns or increased temperatures can affect soil water content and make the conditions unsuitable for the species. Overall, they have great potential to support its growth, especially if

managed wisely. Success in cultivating depends on proper water management, adequate fertilisation, and efforts to maintain the balance of the peat ecosystem to ensure sustainable production.

Table 4 explains that the chemical and physical fertility of peatlands is a major constraint in rumbia palm cultivation. The study sites can be categorised into three land suitability classes: S1 (highly suitable), S2 (moderately suitable), and S3 (marginally suitable). There are just a few short-term limiting factors that can be improved through the application of science and technology when assessing the suitability and limitations for cultivation. These include NA (nutrient availability, such

Table 4. Actual suitability of rumbia palm cultivation in peatlands based on peat depths.

Parameters	Peat depths (cm) related to rumbia palm land suitability (in brackets)			
	50–100	100–200	200–300	>300
Temperature (TC)				
Average temperature, °C	31 (S1)	31 (S1)	31 (S1)	31 (S1)
Wet moisture (WM)	443 (S1)	468 (S1)	470 (S1)	472 (S1)
Rainfall, mm	3,128 (S1)	3,128 (S1)	3,128 (S1)	3,128 (S1)
Rooting media (RC)				
Peat depth, cm	80 (S1)	125 (S1)	250 (S2)	450 (S3)
Nutrient retention (NR)				
Peat CEC, cmol kg ⁻¹	20 (S2)	17 (S2)	10 (S3)	8 (S3)
pH H ₂ O	4.50 (S1)	4.40 (S1)	3.90 (S2)	3.50 (S2)
Organic C, %	41.96 (S1)	43.50 (S1)	49.11 (S1)	48.73 (S1)
Nutrient availability (NA)				
N total, %	1.79 (S2)	1.78 (S2)	1.99 (S2)	1.95 (S2)
P ₂ O ₅ , kg·ha ⁻¹	3.29 (S2)	3.20 (S2)	3.15 (S2)	3.10 (S2)
K ₂ O, kg·ha ⁻¹	11.08 (S2)	11.02 (S2)	9.97 (S2)	9.21 (S2)
Sulphidic hazards (XS)				
Depth of sulphidic layers, cm	100 (S1)	105 (S1)	107 (S1)	110 (S1)
Danger of flooding (FH)				
Flood depth, cm	-15 (S1)	-17 (S1)	-18 (S1)	-20 (S1)
Actual suitability	S1-NA-NR	S1-NA-NR	S2-NA-NR	S3-NA-NR

Note: S1 – highly suitable, S2 – moderately suitable, S3 – marginally suitable; CEC – cation exchange capacity. Land suitability was determined only based on the suitability of potential land and water resources for rumbia palm. Source: Field survey and laboratory analyses (2025).

as N, P, and K), A (soil acidity), and NR (nutrient retention, including organic C, and CEC). Peat depth (1–3 m) is also a limiting factor, particularly for peat layers deeper than 3 m.

Improving the suitability of peatlands for rumbia palm cultivation

The actual suitability of peatlands is determined by their current land-use characteristics, without any additional treatment or enhancement. Table 5 lists several initiatives to improve actual suitability to its potential level. Based on the limiting characteristics, each peatland depth layer has its own suitability class. With limiting factors such as N, P, and K nutrients, soil acidity, and CEC, the actual land suitability classes for peatland depths of 50–100 cm and 100–200 cm are S1-NA, NR; S2-NA, NR, respectively, while S3-NA, NR applies to peatland depths of 200–300 cm and >300 cm. The primary limiting criteria for deeper peatland layers, as listed above, classify them as marginally suitable (S3).

Depending on the type of limiting factors, the potential suitability is defined as peatland suitability after receiving im-

provements inputs such as fertilisation, drainage, and irrigation. After determining suitability class for each peat depth, it was found that there were no limiting factors and that these peatland depths had land suitability class S1. With CEC and pH as limiting factors, its suitability class was S1-NR for peatland depths of 100–200 cm and 200–300 cm. With pH and CEC as limiting criteria, its peatland suitability was S2-NR for depths greater than 300 cm. Inputs such as liming and the application of soil ameliorants (e.g. KCl fertiliser) with minor improvements (+) can still be applied to address or manage potential suitability, resulting in a potential land suitability class S2-NR (moderately suitable).

To address or manage potential suitability and improve peatlands to the potential land suitability class S2-NR (moderately suitable), inputs such as soil ameliorants and liming with minor improvements (+) can still be applied (Table 5). However, to achieve S1 uniformity, it is necessary to apply soil ameliorant and liming with high improvements (++). This finding is consistent with the results reported by other workers (Chua et al. 2021).

Table 5. Efforts to improve actual suitability to potential suitability of peatlands.

Peatland depth, cm	Actual suitability	Given inputs	Improvement level	Potential suitability
50–100	S1-NA, NR	Soil ameliorant, GWT control, no burning, rewetting, keep peatlands flooded.	++	S1
100–200	S1-NA, NR	Soil ameliorant, GWT control, no burning, rewetting, keep peatlands flooded.	++	S1-NR
200–300	S2-NA, NR	Soil ameliorant, GWT control, no burning.	+	S1-NR
>300	S3-NA, NR	Soil ameliorant, GWT control, no burning.	+	S2-NR

Note: S1 – highly suitable; S2 – moderately suitable; S3 – marginally suitable; NA – nutrient availability (N, P, K); NR – nutrient retention (organic C, CEC); GWT – groundwater table; ++ – improving of two level in peatland suitability class; + – improving of one level in peatland suitability class. Field survey and laboratory analyses (2025).

Rainfall and temperature have a significant influence on rumbia palm growth and are also key indicators in assessing the suitability of peatland for its cultivation. These climatic factors strongly affect rumbia palm productivity both before and after harvest. Peatlands frequently experience natural phenomena such as pronounced climate variability and rising temperatures. Farmers and land users in peatland areas typically adopt agricultural practices that are adapted to seasonal and weather conditions to mitigate the impacts of climate change and rising temperatures. According to data from the study site, the mean air temperature between 2000 and 2024 was 30 °C, indicating highly suitable conditions for rumbia palm cultivation.

Waterlogging is essential for rumbia palm growth. In aerobic conditions, however, a shallow and oxidised pyrite layer often becomes a limiting factor due to the resulting very acidic pH in peatland environments. As iron sulphide minerals become more prevalent, the soil acidity increases and may adversely affect plant productivity. The pyrite layer can be managed most effectively by regulating the groundwater level and applying soil ameliorants such as lime. These measures can raise the peatland suitability class from S3 to S2 and help the soil pH return to near-neutral.

The expansion of rumbia palm cultivation often raises concerns regarding the risk of waterlogging in peatlands. They may become inundated through two main mechanisms: sea tides and river tides. During the oxidation process, water serves as an essential reaction medium, and the rate of infiltration directly effects the rate of oxidation. Effective soil and water management is therefore crucial in addressing the pyrite problem. Pyrite can be controlled by farmers through the use

of tertiary canals that help maintain the groundwater level. These channels are designed to regulate the water supply during high and low tides, thereby reducing the risk of flooding during the rainy season and preventing drought during the dry season. Drainage management systems within the channels, particularly tertiary ones, can inhibit pyrite oxidation, which is otherwise detrimental to soil and plants. Based on data from the study site, waterlogging was indicated by flood depths ranging from –15 to –20 cm below ground level (classified as S1), making the area highly suitable for rumbia palm cultivation.

Peat depth has a significant influence on rumbia palm cultivation. The deeper the peat, the more degraded its characteristics tend to be compared with shallow peatlands. The nutrient content of peat decreases with depth, and the root system of the rumbia palm cannot penetrate far enough to reach the substrate, or bottom layer, which usually consists of sediment richer in mineral nutrients. Furthermore, when rumbia palms are planted on deep peat, their root systems are unable to provide adequate support, causing the trees to lean and eventually collapse. Deep peat is therefore categorised as marginally suitable (S3).

Essential nutrients (N, P, K) need to be taken into account, as rumbia palm productivity increases when these nutrients are available in sufficient amounts. One of the main constraining factors at the study sites is the lack of macronutrients. The low phosphate and potassium concentrations in peatlands are primarily caused by soil pH, potassium leaching by water, excessive potassium uptake by rumbia palm, and the insufficient application of potassium fertiliser by farmers, which does not meet the peatland requirements. Phosphate and potassium fertilisers can

be applied in adequate quantities to sustain rumbia palm productivity in peatlands, thereby overcoming this limitation. KCl fertiliser and natural phosphate are two fertilisers that farmers frequently apply to their fields. Adequate nutrient availability can enhance rumbia palm yield, with application rates of 100 kg·ha⁻¹ of KCl fertiliser and 150 kg·ha⁻¹ of natural phosphate, respectively.

Water overflow is important factor in rumbia palm cultivation. Climate conditions affect its planting. The type of overflow, land characteristics, and land typology must all be taken into account when managing water for agricultural development in peatlands. There are two distinct seasons in tidal peatlands: the rainy season and the dry season. To prevent flooding, rumbia palm should be planted during the dry season. Limiting factors for its planting during the first season, which runs from November to April, include flooding caused by climate change, tidal water, and heavy rainfall. Prolonged inundation may drown rumbia palm plants, leading to serious problems such as root system rot. Land in tidal zones needs to be managed with appropriate micro-water control when growing rumbia palm.

The construction of water channels is planned with a width of about 30 cm and a depth of around 20 cm, positioned between plots or beds approximately 4 m wide. During the dry season these channels facilitate the entry of tidal water into the land. Thereafter, from planting to harvest, the water level in the beds needs to be maintained at a constant level. Two weeks prior to planting, a systemic herbicide can be applied to the beds once the tide has entered the channel. These findings are also supported by other workers (Armanto et al. 2025d).

Some challenges of *Metroxylon sagu* cultivation in peatlands

Although peatlands were assessed as highly suitable for *M. rumphii* cultivation, its use in these areas remains limited. This disparity suggests that widespread adoption within regional land-use systems is not determined by ecological suitability alone. These findings are consistent with those reported by other researchers (Choi et al. 2024).

From an ecological standpoint, *M. rumphii* possesses characteristics that closely correspond to the physico-chemical and hydrological conditions of peatlands. The species can tolerate prolonged flooding, low oxygen levels, and acidic substrates – conditions frequently encountered in the peatlands of South Sumatra. Its natural distribution demonstrates considerable adaptive capacity particularly in areas surrounding riverine peat domes, backswamps, and persistently flooded depressions. These observations support the notion that *M. rumphii* could serve as a native paludiculture crop capable of maintaining peat moisture, reducing fire risks, and contributing to ecological restoration. Despite these ecological advantages, the species is not currently prioritised in restoration initiatives, which typically focus on commercially recognised species such as Jelutong (*Dyera costulata* (Miq.) Hook.f) or fast-growing species such as *Melaleuca cajuputi* Powell. Other research findings are consistent with our results (Armanto et al. 2023, Terzano et al. 2023).

Socioeconomic considerations have a stronger correlation with the restricted adoption of *M. rumphii*. Rumbia yields comparatively low short-term financial returns when compared to other peatland crops. Its harvest cycle is prolonged, lo-

cal markets for rumbia-based products (such fibre, starch, or thatch materials) are underdeveloped, and the commodity is thought to have little economic value. Moreover, modernisation of local food systems has lessened the traditional reliance on rumbia starch, further weakening its market relevance. These socio-economic limitations draw attention to a crucial-point: ecological fit does not always translate into livelihood desirability, and local communities are unlikely to accept it in the absence of supportive market institutions. Other research findings are consistent with our results (Nurda et al. 2020, Monda et al. 2022).

An additional limitation is posed by institutional and governance constraints. Peatlands in South Sumatra are primarily designated for large-scale land uses such as agriculture, industrial plantations, or conservation areas with stringent management regulations. There is little policy space for the production of native species like *M. rumphii* under such systems. Although paludiculture is increasingly promoted by current peatland restoration frameworks, there are currently no clear incentives for incorporating underutilised species. As a result, even if these species may not be as ecologically suitable as *M. rumphii* in certain peatland environments, restoration initiatives typically focus on species with greater market value and regulatory support. These findings are consistent with those of other researchers (Lupascu and Wijedasa 2021).

M. rumphii offers several clear advantages over other paludiculture options, which warrant a reevaluation of its role. The species can strategically contribute to long-term hydrological stabilisation and is particularly well suited to deep, permanently submerged peat layers. Its relevance for community-based peatland

management is emphasised by its potential multifunctional benefits, including food security, fibre production, cultural heritage, and ecosystem resilience. However, the realisation of these advantages is limited by the absence of institutional support and organised value chains. These findings are consistent with those reported by other researchers (Budiman et al. 2020, Yuwati et al. 2021).

The results also indicate that reviving rumbia farming could make a significant contribution to the restoration of sustainable peatlands. *M. rumphii* is a peat-native species that supports low-impact livelihoods and ecosystem-based restoration, as it can thrive without drainage. Without compromising the integrity of the peat, community-led rumbia planting could enhance hydrological recovery, improve biodiversity, and provide non-timber forest products. Promoting *M. rumphii* therefore offers an opportunity to integrate the socio-cultural revitalisation of traditional knowledge with ecological restoration.

Comparison with other species for peatland restoration

Compared with commonly promoted peatland restoration species, rumbia palm uniquely provides hydrological compatibility, enhances biodiversity, and delivers earlier economic benefits, addressing a major limitation of currently selected restoration species. Comparative list of local species suitable for peatland restoration is summarised in Table 6.

Study limitations

It is challenging to fully assess growth performance across peat typologies due to the lack of long-term planting studies. Because of habitat deterioration and land-

Table 6. Comparative list of local species for peatland restoration.

Species	Rewetted peatlands	Biodiversity contribution	Economic benefits	Economic return (years)	Limitations
Rumbia palm (<i>Metroxylon sagu</i> Rottb.)	Very high (native, waterlogging tolerant)	High (supports understory and microhabitats)	High and diversified (sago starch, leaves, fibre)	Medium (7–10)	Limited large-scale adoption
Jelutong (<i>Dyera costulata</i> (Miq.) Hook.f)	High (peat-adapted tree)	Medium (closed canopy)	Medium (latex)	Long (15–20)	Slow return, market dependence
Meranti (<i>Shorea balangeran</i> (Korth.) Burck)	Medium-high	Low-medium	Medium (timber)	Very long (20–30)	Long rotation, drainage sensitivity
Gelam (<i>Melaleuca cajuputi</i> Powell)	Medium	Low	Low-medium (fuelwood, oil niche)	Medium (7–10)	Low biodiversity value
Sengon (<i>Falcataria falcata</i> (L.) Greuter & R.Rankin)	Low-medium	Low	Medium (timber)	Short-medium	Poor under high water table
<i>Acacia</i> spp. (exotic)	Low	Very low	High (short-term pulp)	Short (5–7)	Ecologically incompatible

Source: Field survey and literature review (2025).

scape change, field surveys of natural rumbia stands may not accurately reflect the species’ environmental amplitude. Furthermore, a comprehensive economic analysis of rumbia-based value chains – which is essential for determining the viability of livelihoods – is absent from the study. Hydrological modelling of rumbia stands, experimental paludiculture trials, and detailed market analyses of products derived from rumbia would all be valuable for future research.

Overall, the results underscore the need to reconsider the applicability of *M. rumphii* beyond specific agronomic or ecological assessments. The species is clearly compatible with peatland conditions, yet institutional, market, and socioeconomic factors constrain its potential. To fully realise the role of rumbia as a key species

for sustainable peatland management in South Sumatra, a more comprehensive strategy integrating ecological restoration, livelihood diversification, and policy innovation is required.

Conclusions

Peatland acidity, macronutrients (N, P, K), and peat depth are considered as temporary limiting factors. Peatlands were assessed as highly suitable for rumbia palm cultivation in terms of their actual suitability class (S1-NA, NR). Potential suitability class can be optimally achieved through liming, fertilisation, and groundwater level regulation under high-level management (++) , thus reaching potential suitability S1 (very suitable). Moderate manage-

ment (+), involving only groundwater level control, can also achieve the potential suitability S1, but not optimally. Although rumbia palm is resistant to waterlogging, optimal production is achieved through an integrated water management system and planting at a peat depth of 50–100 cm. Overall, improving rumbia palm suitability on peatlands can be achieved relatively easily and at low cost by local farmers, while peatland restoration can be carried out simultaneously without additional expense or field work.

Despite *M. rumphii*'s high degree of ecological suitability - it thrives in acidic, wet, and nutrient-poor peat environments – its practical application remains underdeveloped. Native but underutilised species such as *M. rumphii* receive minimal institutional support under current peatland restoration frameworks, which tend to prioritise economically valuable or fast-growing species. Nonetheless, *M. rumphii* offers significant ecological and cultural benefits that merit renewed attention. It can contribute to biodiversity enhancement, fire prevention, hydrological stabilisation, and the preservation of traditional knowledge systems as a native paludicultural species. Its compatibility with persistently flooded peatlands makes it particularly important for long-term ecosystem recovery. Therefore, incorporating *M. rumphii* into peatland restoration plans provides an opportunity to balance sustainable rural livelihoods with ecological restoration. In conclusion, reconsidering the suitability of *M. rumphii* requires a shift in perspective – from regarding the species merely as a wild plant to recognising it as a vital component of livelihood development and sustainable wetland restoration. With appropriate institutional, scientific, and financial support, *M. rumphii* has the potential to make a significant contri-

bution to the management of South Sumatra peatlands in the future.

References

- ARMANTO M.E. 2019a. Improving rice yield and income of farmers by managing the soil organic carbon in South Sumatra landscape, Indonesia. *Iraqi Journal of Agricultural Sciences* 50(2): 653–661. <https://jcoagri.uobaghdad.edu.iq/index.php/intro/article/view/665/545>
- ARMANTO M.E. 2019b. Comparison of Chemical Properties of Peats under Different Land Uses in South Sumatra, Indonesia. *Journal of Ecological Engineering* 20(5): 184–192. <https://doi.org/10.12911/22998993/105440>
- ARMANTO M.E., ADZEMI M.A., WILDAYANA E., IMANUDIN M.S. 2013. Land evaluation for paddy cultivation in the reclaimed tidal lowland in Delta Saleh, South Sumatra, Indonesia. *Journal of Sustainability Science and Management* 8(1): 32–42. <https://repository.unsri.ac.id/23932/1/Artik003-2013.pdf>
- ARMANTO M.E., WILDAYANA E., IMANUDIN M.S. 2025a. Assessing Soil Nutrient and Biomass Contributions to Peatland Formation. *Planta Tropika Journal* 13(1): 91–103. <https://doi.org/10.18196/pt.v13i1.24233>
- ARMANTO M.E., WILDAYANA E., SYAKINA B. 2023. Deciphering the anthropogenic challenges of peat swamp forest degradation to improve awareness and emphasis on restoration in South Sumatra. *Forestry Ideas* 29(2): 207–215. https://forestry-ideas.info/issues/issues_Index.php?journalFilter=73
- ARMANTO M.E., WILDAYANA E., SYAKINA B. 2025b. Leveraging selected Local Wisdom Species in developing peatland restoration in South Sumatra, Indonesia. *Visions for Sustainability* 23, 11731: 123–146. <https://doi.org/10.13135/2384-8677/11731>
- ARMANTO M.E., WILDAYANA E., SYAKINA B. 2025c. Reimagining Life Quality of Farmers in South Sumatra Peatlands, Indonesia. *Research on World Agricultural Economy* 6(1): 146–158. <https://doi.org/10.36956/rwae.v6i1.1153>

- ARMANTO M.E., WILDAYANA E., SYAKINA B. 2025d. Emphasizing Local Wisdom in Peatland Restoration in South Sumatra Indonesia. *Polish Journal of Environmental Studies* 34(2): 1017–1025. <https://doi.org/10.15244/pjoes/187124>
- ASTM INTERNATIONAL 2025. *ASTM D2974-25: Standard Test Methods for Determining the Water (Moisture) Content, Ash Content, and Organic Material of Peat and Other Organic Soils*. West Conshohocken, PA: ASTM International. <https://doi.org/10.1520/D2974-25E01>
- BAGASBAS J.M., BARROCA R.B. 2020. Development and evaluation of sago (*Metroxylon sago*) pith extractor. *Journal of Agricultural Engineering* 51(3): 140–147. <https://doi.org/10.4081/jae.2020.1058>
- BRGM (BADAN RESTORASI GAMBUT DAN MANGROVE) 2022. Peat and Mangrove Restoration Agency Performance Report 2022 [Laporan Kinerja. Badan Restorasi Gambut dan Mangrove 2022]. 113 p. (in Indonesian). <https://brgm.go.id/publikasi/>
- BUDIMAN I., BASTONI S., SARI E.N.N., HADI E.E., ASMALIAH H., SIAHAAN H., JANUAR R., HAPSARI R.D. 2020. Progress of paludiculture projects in supporting peatland ecosystem restoration in Indonesia. *Global Ecology and Conservation* 23, e01084. <https://doi.org/10.1016/j.gecco.2020.e01084>
- BYG A., NOVO P., KYLE C. 2023. Caring for Cinderella – Perceptions and experiences of peatland restoration in Scotland. *People Nature* 5(2): 302–312. <https://doi.org/10.1002/pan3.10141>
- CHOI H.-A., SONG C., LIM C.-H., LEE W.-K., YANG H., KIM R. 2024. Synthesizing recent trends in interventions and key ecosystem services in Indonesian peatland. *Land* 13(3), 355. <https://doi.org/10.3390/land13030355>
- CHUA S.N.D., KHO E.P., LIM S.F., HUSSAIN M.H. 2021. Sago palm (*Metroxylon sago*) starch yield, influencing factors and estimation from morphological traits. *Advances in Materials and Processing Technologies* 8(2): 1845–1866. <https://doi.org/10.1080/2374068X.2021.1878702>
- DIMARA P.A., PURWANTO R.H., SUNARTA S., WARDHANA W. 2021. The spatial distribution of sago palm landscape Sentani watershed in Jayapura District, Papua Province, Indonesia. *Biodiversitas* 22(9): 3811–3820. <https://doi.org/10.13057/biodiv/d220926>
- LUPASCU M., WIJEDASA L.S. 2021. Paludiculture as a sustainable land use alternative for tropical peatlands: a review. *Science of the Total Environment* 753, 142111. <https://doi.org/10.1016/j.scitotenv.2020.142111>
- MONDA Y., KUWAHARA S., AOKI Y., SUZUKI H., KANEKO T., KOZAN O., MUHAMMAD A., SUSANTI R., GUNAWAN H., KANZAKI M. 2022. Productivity of sago palms on smallholder plantations after rewetting in previously drained peatland: a case study on Tebing Tinggi Island, Riau Province, Indonesia. *Tropics* 31(1): 11–32. <https://doi.org/10.3759/tropics.MS21-15>
- NURDA N., NOGUCHI R., AHAMED T. 2020. Change detection and land suitability analysis for extension of potential forest areas in Indonesia using satellite remote sensing and GIS. *Forests* 11(4), 398. <https://doi.org/10.3390/f11040398>
- SASAKI Y., ANDO H., KAKUDA K.-I., MELLING L., WATANABE A. 2025. Efficient nitrogen fertilization for sustainable sago palm (*Metroxylon sago* Rottb.) cultivation in Tropical Peatland. *Plant Production Science* 28(1): 23–33. <https://doi.org/10.1080/1343943X.2024.2423977>
- SYAKINA B., NOR R.M., ARMANTO M.E. 2024a. Elucidating indigenous farmers' avoidance of deep peatlands for food crop farming in South Sumatra Province, Indonesia. *Forestry Ideas* 30(1): 3–15. https://forestry-ideas.info/issues/issues_Index.php?journalFilter=74
- SYAKINA B., NOR R.M., ARMANTO M.E. 2024b. Linkages of peatland degradation and rural poverty in development scenarios of peatland restoration. *Geografia-Malaysian Journal of Society and Space* 20(1): 85–98. <https://doi.org/10.17576/geo-2024-2001-06>
- TERZANO D., TREZZA F.R., REZENDE M., MALATESTA L., LEW SIEW YAN S., PARISH F., MOSS P., BRESCIANI F., COOKE R., DARGUSCH P., ATTORRE F. 2023. Prioritization

- of peatland restoration and conservation interventions in Sumatra, Kalimantan and Papua. *Journal for Nature Conservation* 73, 126388. <https://doi.org/10.1016/j.jnc.2023.126388>
- WILDAYANA E., ARMANTO M.E. 2018. Dynamics of Landuse Changes and General Perception of Farmers on South Sumatra Wetlands. *Bulgarian Journal of Agricultural Science* 24(2): 180–188. <http://www.agro-journal.org/24/02-02.html>
- WILDAYANA E., ARMANTO M.E., ZULKIFLI I., RADIATMOKO I.A., UMAR S.A., SYAKINA B., OKTAVIA R., SARI E. 2018. Surviving Strategies of Rural Livelihoods in South Sumatra Farming System, Indonesia. *E3S Web of Conferences* 68, 02001. 9 p. <https://doi.org/10.1051/e3sconf/20186802001>
- YAMAMOTO Y., ISAMU Y., TETSUSHI Y., AKIRA M., YULIUS B.P., SIGIT D., JERMIA L., FOH SHOON J., ALBERTUS F.I., AYSYAH A.A. 2020. Characteristics of Growth and Starch Productivity of Wild Sago Folk Variety 'Manno' Grown near Jayapura, Papua, Indonesia. *Tropical Agriculture and Development* 64(3): 135–145. <https://doi.org/10.11248/jsta.64.135>
- YUWATI T.W., RACHMANADI D., PRATIWI R., TURJAMAN M., INDRAJAYA Y., NUGROHO H.Y.S.H., QIROM M.A., NARENDRA B.H., WINARNO B., LESTARI S. 2021. Restoration of degraded tropical peatland in Indonesia: A review. *Land* 10(11), 1170. <https://doi.org/10.3390/land10111170>