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Local wisdom of the Lingga Malay Community in harvesting and transporting sago in Lingga District, Riau Islands, Indonesia

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Abstract. *Al Manar P, Zuhud EAM, Andarwulan N, Fauzi AM, Bintoro MH, Hikmat A, Hermanida S. 2026. Local wisdom of the Lingga Malay Community in harvesting and transporting sago in Lingga District, Riau Islands, Indonesia. Biodiversitas 27 (4): d270415. https://doi.org/10.13057/biodiv/d270415.* Sago (*Metroxylon sagu*) plays an important role in the food system, culture, and ecological resilience of coastal communities in Indonesia, including the Lingga Malay Community in the Riau Islands, Indonesia. However, systematic documentation of traditional ecological knowledge (TEK) related to sago harvesting and transportation in this region remains limited. This study aimed to analyze local wisdom practices associated with sago harvesting and transportation among the Lingga Malay Community. A qualitative approach was applied through in-depth interviews with 100 informants across ten villages, participatory observation, and a literature review. Data were analyzed using thematic analysis supported by coding and triangulation techniques. The results reveal that the community possesses a well-developed TEK system for identifying harvestable sago palms based on morphological indicators and ecological conditions. Harvesting practices combine traditional techniques with selective semi-mechanized tools adapted to local environmental constraints. In addition, transportation systems are primarily water-based, using *rakit* and small motorized boats (*pompong*), reflecting adaptive strategies to the archipelagic and riverine landscape of Lingga. The utilization of sago residues further demonstrates resource-efficient practices embedded in local socio-ecological systems. These findings highlight the role of traditional knowledge in supporting adaptive resource management and sustaining local livelihoods in island ecosystems.

Keywords: Farmer, food security, *Metroxylon sagu*, sustainable, traditional ecological knowledge

INTRODUCTION

Sago (*Metroxylon sagu* Rottb.) is a member of the Arecaceae family and is widely distributed across Southeast Asia, including Indonesia, Malaysia, the Philippines, and Papua New Guinea (Naim et al. 2016; Al Manar et al. 2023). It predominantly grows in lowland areas at elevations of 0-400 m above sea level, whereas growth at higher elevations is slower and associated with lower starch yields (Yamamoto et al. 2020a). Sago has high potential as a food, economic, ecological, and cultural resource and is recognized as one of the most efficient carbohydrate-producing crops (Konuma 2018; Monda et al. 2022). Sago ecosystems, particularly those associated with peatlands and waterlogged environments, play an important role in maintaining biodiversity and ecological functions, and the species' high tolerance to marginal conditions makes it a strategic resource for climate change adaptation and food security (Flach 1997; Bintoro et al. 2018).

Beyond its material functions, sago plays a significant symbolic and social role in many coastal and island communities in Southeast Asia, where collective harvesting and communal consumption reinforce social networks and cultural identities (Al Manar et al. 2023; Morni et al. 2024). In Indonesia, sago remains central to food security and cultural continuity in both the eastern and western regions, including the Lingga District in the Riau Islands (Flach 1997; Al Manar et al. 2023). The utilization of sago by the Lingga Malay Community has persisted for centuries and expanded notably following the relocation of the Malay Kingdom's center from Hulu Riau to Daik Lingga in 1787 under Sultan Mahmud Riayat Syah (Al Manar et al. 2023). In this region, sago functions not only as a staple food but also as an integral component of social organization, cultural expression, and local economies. Knowledge related to sago harvesting and transportation has been transmitted across generations, forming a locally embedded system of practices that reflects close interactions with the surrounding environment.

Local wisdom in natural resource use is closely associated with traditional ecological knowledge (TEK) and ethnobiological systems, in which ecological understanding and cultural practices co-evolve to sustain both ecosystems and livelihoods (Gómez-Baggethun et al. 2013; Adade Williams et al. 2020). Such knowledge systems contribute to resource sustainability, social cohesion, and adaptive capacity in the face of environmental and socio-economic change (Raj et al. 2018; Widianingsih et al. 2023; Zurba and Papadopoulos 2023; Budiman and Oue 2025). In sago agroecosystems, TEK plays a key role in maintaining ecological balance in peatland and wetland environments by regulating harvesting intensity, biomass utilization, and minimizing ecosystem disturbance. Previous studies on sago-based communities, such as the Marind-Anim in Papua (Kadir et al. 2022) and communities in the Meranti Islands (Ayulia et al. 2020), have emphasized the cultural and subsistence roles of sago. However, these studies provide a limited analysis of adaptive harvesting and transportation strategies within archipelagic and riverine landscapes.

Despite the longstanding importance of sago in the Lingga District, systematic documentation of local wisdom related to harvesting timing, extraction techniques, and transportation systems remains scarce. Previous studies, including those by Al Manar et al. (2023) and Al Manar et al. (2024), have primarily focused on traditional sago use and plant morphological characteristics without examining in-depth how local knowledge shapes decisions regarding harvest timing, work organization, and transportation strategies in island landscapes. Other studies of sago-based communities in Papua and the Meranti Islands have also tended to emphasize cultural and subsistence aspects with limited attention to adaptive harvesting and transportation systems within specific ecological contexts. Therefore, there is an imbalance in research regarding how local wisdom functions as an integrated knowledge system in sago harvesting and distribution practices. Simultaneously, socio-economic transformation, modernization, and globalization pose risks to the continuity of this knowledge, particularly in the absence of formal documentation (Abas et al. 2022; Kurnia et al. 2022; Syamsi et al. 2024). Addressing this gap is essential for preserving cultural heritage and strengthening sustainable local resource management. Such efforts are also relevant to broader sustainability agendas, including food security and ecosystem conservation (FAO 2021).

Therefore, this study aimed to explore and analyze the local wisdom practices of the Lingga Malay Community in relation to sago harvesting and transportation. Specifically, this study examines (i) local taxonomic criteria for determining sago harvest maturity, (ii) work organization and wage systems in harvesting and transportation activities, (iii) transportation modes and their adaptation to archipelagic environments, and (iv) the utilization of sago residues as indicators of ecological and economic sustainability. By focusing on the integration of ecological knowledge and adaptive practices, this study contributes to the understanding of the role of TEK in supporting sustainable management and biodiversity conservation in sago agroecosystems.

MATERIALS AND METHODS

Study area

This study was conducted from July to August 2025 in Lingga District, Riau Islands Province, Indonesia (Figure 1). Lingga District, officially established in 2003 through Law No. 31/2003, is geographically located between 0°20’N-0°40’S and 104°-105°E. The region is bordered by Batam City and the North Natuna Sea to the north, the Bangka Sea and Berhala Strait to the south, Indragiri Hilir to the west, and the North Natuna Sea to the east. Lingga has a humid tropical climate with an average annual rainfall of 244.1 mm in 2024, and its topography is dominated by steep slopes, with more than 76.9% of the area having gradients above 15% (Statistics of Lingga District 2024).

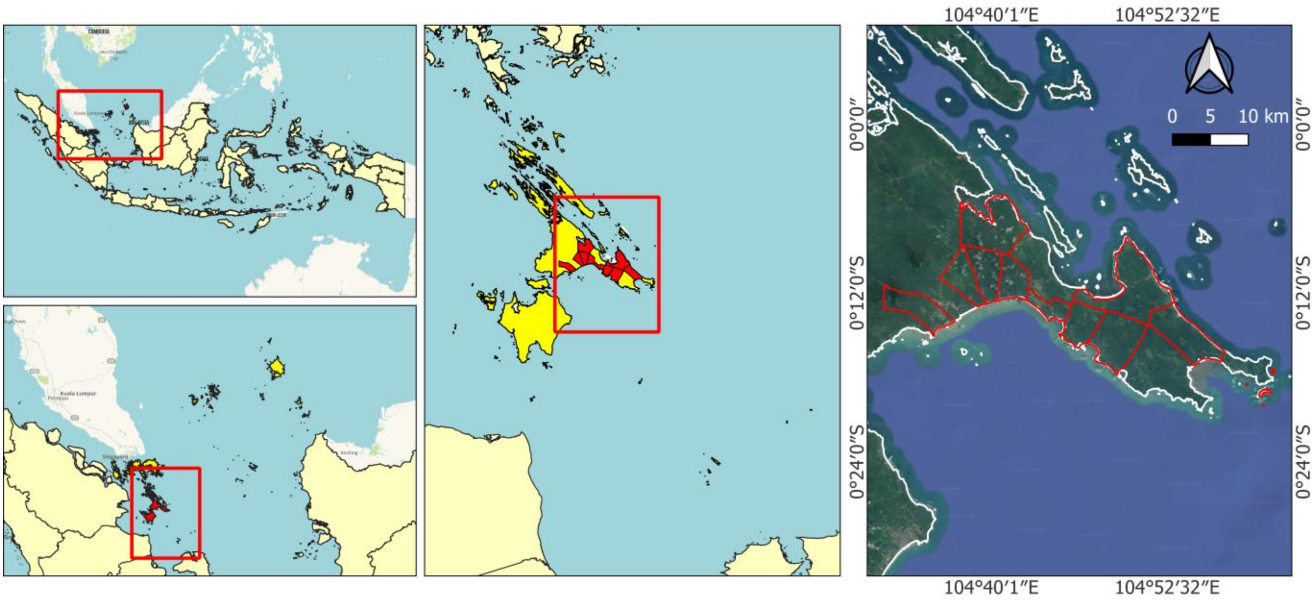

Figure 1. Map of research location in Lingga District, Riau Islands Province, Indonesia

Ecologically, Lingga consists of extensive wetlands, peat swamps, and riverine systems that provide favorable conditions for the natural growth of sago. The archipelagic geography and high rainfall contribute to the maintenance of freshwater availability, which is essential for the productivity of sago palms. Culturally, Lingga has a long history as the former center of the Lingga Sultanate, where sago has become embedded in local dietary patterns and socio-cultural practices. These characteristics make Lingga a representative case for understanding traditional ecological knowledge (TEK) in sago management and a strategic site for analyzing how local communities adapt their livelihoods to ecological constraints and opportunities. The combination of challenging topography, humid climate, and cultural heritage underscores the importance of studying local wisdom regarding sago harvesting and transportation within this region.

Data collection

The data for this study were collected using a qualitative research approach through semi-structured in-depth interviews, participatory observations, and a literature review. Interviews were guided by predefined themes to explore traditional ecological knowledge (TEK) related to sago management, including local criteria for identifying harvest-ready sago palms (*sorong muda*), harvesting and extraction practices, transportation modes and decision-making factors, labor organization and wage systems, and the cultural significance of sago within the Lingga Malay Community.

A purposive sampling strategy was applied to select informants with direct experience and knowledge of sago harvesting and transportation. The study involved 100 male informants aged between 25 and 70 years from ten villages in Lingga District (Merawang, Panggak Laut, Nerekeh, Musai, Kerandin, Pekaka, Keton, Limbung, Resun Pesisir, and Teluk), which represent major sago-producing areas. Approximately 80% of the informants were smallholder sago farmers directly involved in harvesting, while the remainder were engaged in transportation and primary processing activities. All informants were male, reflecting the cultural division of labor within the Lingga Malay socio-cultural system, in which physically demanding activities such as felling palms, cutting logs, and transporting sago through forested and riverine environments are predominantly undertaken by men. This gender composition represents a culturally specific labor structure and constitutes a limitation of this study, as it does not capture women's perspectives, particularly in post-harvest processing and household-level utilization.

Prior to data collection, informed consent was obtained from all informants after explaining the objectives and scope of the study, ensuring voluntary participation and the confidentiality of responses. To ensure data reliability and credibility, member checking was conducted on 20 interview transcripts (20%) with 10 key informants to verify the accuracy of the interpretations. Triangulation was applied by comparing the interview findings with observational data and secondary literature to strengthen the consistency across themes.

Participatory observation was conducted to contextualize and validate the interview findings. The researchers observed harvesting and transportation activities, focusing on the overall workflow, division of labor, use of traditional and semi-mechanized tools, and environmental conditions influencing operational decisions. Observations were systematically recorded through field notes and photographic documentation to support the interpretation of socio-ecological practices. Secondary data were obtained through a literature review of peer-reviewed journals, books, and reports published between 2000 and 2024. The literature review provided contextual support and contributed to the triangulation of primary field data.

Data analysis

Data were analyzed using a descriptive qualitative approach, applying thematic analysis techniques (Braun and Clarke 2006) combined with Miles and Huberman's (1994) interactive analysis model. The analysis was conducted in three main stages: (i) data reduction, (ii) data presentation, and (iii) drawing and verifying conclusions. During the data reduction stage, the interview transcripts and participant observation notes were repeatedly read, coded, and categorized to identify key themes, such as local wisdom practices in sago harvesting, transportation techniques, the role of individual/group cooperation, and socio-economic factors influencing community work patterns. The coding process began with open coding to identify initial concepts from the raw data, followed by axial coding to establish relationships among categories, and finally, selective thematic grouping to construct overarching themes. Data were presented in the form of narrative descriptions, tables, and direct quotes from informants to strengthen the interpretations.

The conclusion-drawing process was conducted inductively by interpreting the relationships between the interview results, observations, and literature. Data validity was strengthened by source triangulation techniques (comparing interview results with observations and literature) and member checking with multiple informants. Theme validation was conducted through iterative discussions among the research team to ensure the consistency, coherence, and interpretative reliability of the identified themes. Data collection and analysis were conducted iteratively until thematic saturation was achieved, as indicated by the absence of new themes emerging from additional data. This analysis also draws on the traditional ecological knowledge (TEK) framework to understand how sago harvesting and transport practices contribute to the sustainability of resource management and the economic resilience of the local communities.

RESULTS AND DISCUSSION

Characteristics of informants

This study involved 100 male informants aged between 25 and 70 years from ten villages in Lingga District, representing the main sago-producing areas in the region. The selection of informants was based on their direct involvement and long-term experience in sago harvesting and transportation activities, ensuring that the data reflected practical knowledge embedded in daily livelihoods. The predominance of male informants is consistent with the socio-cultural context of the Lingga Malay Community, where physically demanding activities, such as felling, cutting, and transporting sago logs, are primarily undertaken by men.

Regarding age distribution, the majority of informants were in the late adulthood category (36-45 years), accounting for 38% of the total respondents, whereas the smallest proportion was represented by younger individuals aged 25-30 years (3%). This pattern reflects the dominance of individuals in their productive working age within sago-related activities, particularly in labor-intensive stages, such as harvesting and transportation. The limited representation of younger individuals may indicate declining interest or reduced engagement in sago-based livelihoods, which are often perceived as physically demanding and less economically attractive than alternative occupations. Similar trends have been widely reported in agricultural systems, where younger generations tend to migrate to non-agricultural sectors, resulting in an aging workforce and reduced labor regeneration (Girdziute et al. 2022; Ngadi et al. 2023). Such demographic conditions may have implications for the continuity of sago production systems, particularly in terms of labor availability and long-term sustainability (Ren et al. 2023). This age structure also influences the distribution of knowledge within the community, as practical skills and experience tend to accumulate among older and more actively engaged individuals.

The variation in age and experience among informants provides a comprehensive representation of knowledge distribution across generations, allowing this study to capture both established practices and potential shifts in traditional ecological knowledge (TEK), which is inherently transmitted through intergenerational learning processes (Sinthumule 2023). Most informants were actively engaged as sago farmers, while others were involved in the transportation and early processing stages, indicating the interconnected nature of labor roles within the sago value chain. This diversity reflects the embeddedness of TEK within everyday socio-ecological practices, where knowledge is shaped by direct interactions with the environment and accumulated experiential learning (Molnár et al. 2024). Such variation in roles is essential for understanding how local knowledge is applied across the different stages of harvesting and transportation, as well as how decision-making processes are collectively formed within the community (Hanazaki 2024).

Traditional knowledge on sago growth stages

Field findings show that the Lingga Malay Community classifies sago palm growth into six locally recognized stages: *pekpah*, *ladung*, *batang sagu*, *batang mutih*, *sorong muda*, and *sorong tua* (Table 1). Each stage was identified using observable morphological indicators, including plant height, leaf length, trunk formation, midrib coloration, and inflorescence appearance. These stages were consistently recognized across the ten studied villages, indicating shared ecological knowledge within the community. The early stages (*pekpah* and *ladung*) correspond to the vegetative phase, when the plant exhibits increasing leaf size and photosynthetic capacity but has not yet formed a visible trunk. The *batang sagu* stage marks the emergence of a clear bole, followed by a *batang mutih*, characterized by whitening of the midrib and a still-soft apical meristem (*umbut sagu*), which is commonly consumed as a vegetable. The *sorong muda* stage is considered the optimal harvesting phase, identified by the emergence of the inflorescence axis and leaf shortening. Informants consistently associated this stage with peak starch accumulation based on empirical observations of yield during processing rather than the direct quantitative starch measurements conducted in this study. In contrast, sorong tua marks the post-maturity phase, when fruit formation begins and starch content declines.

These locally defined stages correspond closely with the scientific descriptions of sago phenology. Previous studies have described the progression from vegetative growth to trunk formation and flowering initiation as key determinants of starch accumulation and harvest timing (Flach 1997; Nabeya et al. 2015; Nakamura 2018). Physiologically, starch accumulation reaches its maximum before or at the onset of flowering, after which it gradually decreases (Chua et al. 2021). The identification of the *sorong muda* as the optimal harvest period is therefore interpreted as a knowledge-based inference grounded in repeated field experience rather than laboratory-based starch testing. This indicates that local decision-making relies on observable phenological indicators that function as practical proxies for starch content.

Table 1. Local terms for sago palm growth stages

Growth stages	Morphological characteristics	Plant age (years)	Description	Category Flach (1997)
Pekpah	The plant height was between 30-50 cm.	1-2	-	Rosette stage
Ladung	The leaves are 60-80 cm long.	2-3	The leaves can now be used to make roofs.	
Batang sagu	Sago plants have a main stem.	3-6	-	Bole formation stage
Batang mutih	The midrib began to turn white.	6-9	*Umbut sagu* can be consumed as a vegetable.	
Sorong muda	Inflorescence stalks appear at the tip of the stem, and the leaves are shortened.	8-12	The sago palm has entered the harvesting stage.	Inflorescence stage
Sorong tua	The fruit begins to form, and the plant begins to die.	> 12	The sago plant has passed its harvest maturity period.	Fruit ripening stage

The recognition of the *batang mutih* as a distinct stage also reflects multifunctional resource use. In this phase, the apical meristem is still suitable for consumption, demonstrating how vegetative and reproductive stages are integrated into food diversification strategies. Rather than relying solely on starch extraction, the community utilizes different plant components at different growth stages, reflecting adaptive management practices within peat swamp ecosystems, where sago thrives naturally.

The close correspondence between local classification and botanical growth models illustrates how traditional ecological knowledge (TEK) operates as a practical system of plant phenological monitoring. Similar complementarities between local and scientific knowledge have been reported in other contexts of tropical resource management (Cebrián-Piqueras et al. 2020; Adade Williams et al. 2020; Haq et al. 2023; Kor et al. 2024; Sheppard et al. 2024). In this context, TEK does not replace scientific measurement but provides an efficient, experience-based system for determining optimal harvest timing under field conditions, where laboratory analysis is not always feasible. In the case of Lingga, documenting this classification system contributes to the understanding of how community-based knowledge supports sustainable harvest timing and agroecosystem management in archipelagic environments. The classification of sago growth stages based on local knowledge is shown in Figure 2.

Sago harvesting system

Sago harvesting in the Lingga District reflects a long-standing body of local ecological knowledge that has been transmitted intergenerationally. Historical accounts indicate that sago forests were already utilized during the Lingga Sultanate period, and contemporary practices continue to rely on accumulated experiential knowledge. Similar patterns of knowledge-based resource management have been documented among the Marind-Anim people in Merauke, Papua, who apply selective cutting strategies to maintain long-term sago availability (Kadir et al. 2022). In Lingga, tree selection is highly selective and primarily based on morphological indicators, particularly trunk diameter, height, leaf condition, and the appearance of the terminal inflorescence.

While Yamamoto et al. (2020a) reported that naturally growing sago in South Sorong requires approximately 15 years to reach harvest maturity and 7-8 years under managed conditions, Lingga farmers generally harvest trees at around eight years of age. Trees selected for felling typically have a trunk diameter of ≥20 cm, height of 10-15 m, yellowing and shortening leaves, and emerging terminal flowers (Figure 3). Scientific evidence indicates that starch content remains relatively high (>20%) during early flowering (≥5 living leaves) and gradually declines to 11.96% (4 leaves) and 8.61% (2 leaves) as physiological vitality decreases (Irawan et al. 2025). Although flowering signals imminent death of the palm and a decline in starch content (Chua et al. 2021), starch is not immediately depleted. This aligns with Lingga farmers' practice of harvesting at the early flowering stages to balance starch yield and tree maturity. Premature harvesting is avoided because young palms have a higher water content than starch.

The harvesting techniques in Lingga are currently semi-mechanical, combining machetes and chainsaws (Figure 4). Machetes are used to clear undergrowth and assist trunk preparation, whereas chainsaws are employed for felling and cutting logs into approximately 1-m sections. This transition mirrors the broader technological shifts observed in the Maluku Islands, where chainsaws replaced axes after the 1980s (Jong 2018). The coexistence of traditional and semi-mechanical tools illustrates adaptive integration rather than technological replacement.

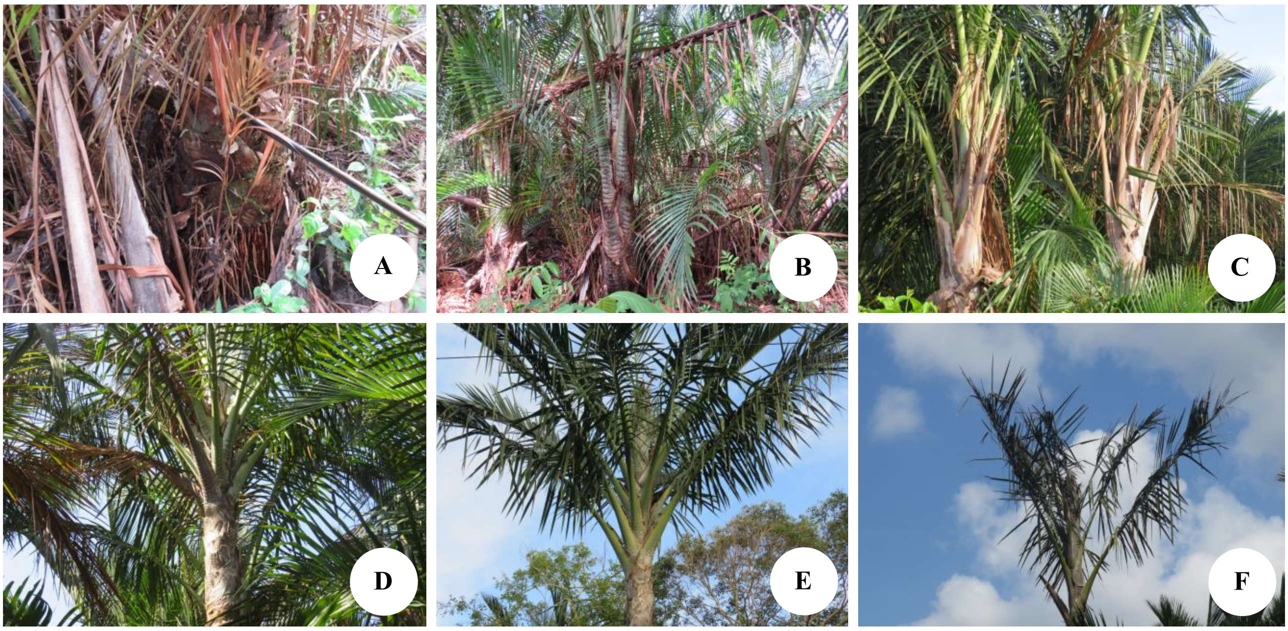

Figure 2. Sago palm growth stages. A. *Pekpah*, B. *Ladung*, C. *Batang sagu*, D. *Batang mutih*, E. *Sorong muda*, F. *Sorong tua*

Fuel consumption in Lingga averages approximately 0.45 L per sago palm, with variation depending on tree diameter and chainsaw condition. Previous studies have shown that fuel consumption during tree felling generally increases with tree size and operational conditions (Popovici 2013; Antonić et al. 2023). Based on field data, the estimated fuel consumption per production cycle (approximately 200 logs yielding 10-15 metric tons of wet sago) suggests an approximate energy use of 0.03-0.045 L per log or 6-9 L per production cycle. This indicates that energy use remains relatively low at the system level, reflecting small-scale, labor-intensive operations rather than industrial logging intensity. Regular daily maintenance, including chain lubrication and inspection, is practiced locally to maintain efficiency, which is consistent with recommendations regarding cutting equipment management (Kovach et al. 2019).

Harvesting activities were conducted systematically, beginning with tree identification and ending with log removal ("*golek*") (Figure 5). Activities generally occur from morning to afternoon to ensure sufficient natural lighting, which is a basic requirement for fieldwork (Odiyur Vathanam et al. 2021). Weather variability significantly affects harvesting decisions. Heavy rainfall reduces operational safety and efficiency, which is consistent with the findings of Ishak et al. (2021) and Trisia et al. (2021), who identified weather instability and limited infrastructure as major constraints in sago-producing regions. These factors indicate that sago harvesting is strongly shaped by environmental conditions and infrastructural limitations and not solely by cultural preference.

On average, harvesting a single sago palm in Lingga, from morphological identification to short-distance skidding, requires approximately 90 min. This duration exceeds that reported for tropical timber felling for meranti using chainsaws (16-17 min) in Papua (Soenarno et al. 2022), but these figures exclude post-felling processes. Traditional sago systems are widely recognized as labor-intensive and dependent on water availability (Nishimura 2018). Additional time in Lingga is associated with wetland conditions and the need for controlled felling techniques to ensure safety.

After felling, the trunks were cleaned and cut into sections (*tual* or log) of approximately 60-100 cm (Figure 6), consistent with the findings of Susanto et al. (2024). Lingga farmers employ a rattan-based body measurement system to standardize log length and demonstrate embodied measurement knowledge. Although sectioning increases the harvesting time, it facilitates transportation and subsequent starch extraction. Similar trunk yields (5-18 logs per tree) have been reported in other regions (Jong 2018; Yamamoto et al. 2020b). In Lingga, each tree produces approximately 10-15 logs, depending primarily on height.

The Lingga community does not harvest sago trees continuously; felling decisions depend on the availability of raw materials in agro-industrial units. When log stocks are sufficient, farmers prioritize processing rather than cutting new trees. In one production cycle, approximately 200 logs are processed, producing 10-15 tons of wet sago within approximately 20 days. This intermittent harvesting pattern prevents trunk deterioration and helps maintain starch quality while also reducing the ecological risks associated with overharvesting, such as increased runoff, soil erosion, and river sedimentation (Flach and Schuiling 1989). However, this study did not include direct measurements of regrowth rates or long-term ecological monitoring; therefore, claims regarding sustainability should be interpreted as indicative rather than quantitatively verified. Similar labor- and capacity-based harvesting strategies have been reported in Seram, Maluku, where communities favor wet sago processing due to the time- and labor-intensive nature of full harvesting (Sasaoka et al. 2014; Bocobo et al. 2022).

Figure 3. Terminal inflorescence of the sago palm

Figure 4. Traditional harvesting tools used by the Lingga Malay Community. A. Machete, B. Chainsaw

Figure 5. Stages of sago harvesting as practiced by the Lingga Malay Community. A. Identifying trees ready to be cut, B. Cleaning sago trunks, C. Determining the direction of felling, D. Cutting sago trunks into1 meter lengths, E. Cleaning the bark of the trunk, F. Felling sago trees, G. Making holes in sago tuals for rolling, H. Rolling sago tuals out of the sago forest

Figure 6. Sago log division size

Harvesting intensity ranges from one to five trees per day, depending on the labor organization. Inland villages tend to harvest individually, whereas coastal communities more commonly adopt group systems owing to their dual livelihoods, particularly fishing. This flexible labor arrangement reflects adaptive livelihood strategies in small-scale rural economies. Cooperative work patterns are also documented in traditional sago systems in New Guinea, where manual processing necessitates collective labor (Nishimura 2018), and farmer group involvement has been shown to enhance household income (Timisela et al. 2022).

Each felled palm produces 10-15 logs, which is comparable to reports by Jong (2018) and Yamamoto et al. (2020b). Log yield depends on trunk height, with farmers managing the full harvesting process, typically handling one to two trees per day. The logs were manually processed using locally crafted hardwood tools made from resak (*Vatica* sp.) and selumar (*Mussaendopsis beccariana*) (Figure 7.A). An iron hook attached at the base (Figure 7.B) facilitates the rolling of heavy logs across the wet peat terrain. These tools reflect locally adapted technological knowledge that enables efficient harvesting under limited mechanization.

Sago felling is generally performed by a single worker, whereas moving the felled trunk (*tual sagu*) requires 1-3 workers due to its substantial weight. Logs are typically rolled in the afternoon to prevent prolonged exposure, which may reduce starch quality. Excessive drying has been shown to cause thermal degradation of sago starch, lowering swelling and gelatinisation capacity (Kamal et al. 2019), and negatively affecting physicochemical properties and industrial performance (Nishimura et al. 2018). In Lingga, log movement is facilitated by a simple wooden rail structure known locally as *rel* (Figure 8). This indigenous technique enables the efficient transfer of heavy trunks from peat forest sites to collection points while minimizing handling losses. The system represents an adaptive local innovation suited to wetland environments, although its efficiency has not been quantitatively compared with mechanized alternatives.

Economic system

Most sago loggers in Lingga also operate small-scale agro-industries, whereas others hire specialized loggers. The wage for felling ranges from IDR 120,000 to 170,000 per tree, including extraction from the forest. Separate payments apply for felling and distribution (IDR 50,000-70,000 per tree) or for gathering only (IDR 7,000-11,000 per tree), depending on the transport distance. Trees may originate from farmers' own plots or be purchased at IDR 80,000-120,000 per tree, which is comparable to the prices in the Maluku Islands (IDR 100,000-150,000 per tree) (Girsang 2018). This wage structure reflects a flexible and multilayered livelihood system in which individuals can participate at different stages of the value chain, including harvesting, transport, and processing. Such diversification of roles contributes to livelihood resilience by allowing households to adjust their involvement based on available labor, capital, and seasonal conditions.

In addition to direct purchases, a traditional profit-sharing system is practiced, whereby one-third of the starch yield is allocated to the tree owner and two-thirds to the processor. This system enables resource access without requiring full ownership, thereby lowering the entry barriers for small-scale processors. This flexible economic arrangement reflects a locally embedded value chain that integrates ownership, labor, and processing within community-based resource management.

This profit-sharing mechanism also has implications for resource sustainability and conservation incentives. Because tree owners receive a direct share of the final starch output, they have an economic interest in maintaining the productivity of sago stands, including allowing trees to reach the appropriate harvest maturity. Similarly, processors benefit from higher starch yields, which encourages selective harvesting practices aligned with phenological indicators identified through traditional ecological knowledge (TEK). Such benefit-sharing arrangements are consistent with findings from recent studies indicating that economic incentives can positively influence conservation behavior and resource management decisions (Nyanghura et al. 2024a; Nyanghura et al. 2024b).

Rather than promoting short-term extraction, this shared-benefit arrangement may support a balance between resource use and regeneration by aligning economic returns with ecological conditions. Previous research has also shown that land users are more likely to adopt sustainable management practices when incentive structures directly link economic benefits to long-term resource productivity (Chizmar et al. 2025). However, the extent to which this system directly contributes to long-term conservation outcomes has not been quantitatively assessed in this study and should therefore be interpreted as a potential rather than a measured effect. This is important, as the effectiveness of benefit-sharing mechanisms in conservation depends not only on economic incentives but also on governance structures and equitable distribution of benefits (Twinamatsiko and Kagoro 2024).

Sago logs transportation system

Sago logs are transported after being rolled out and collected along roadsides or riversides, depending on forest accessibility. Transportation is conducted by land or water, with the route determined by distance and infrastructure conditions. Land transportation is performed using *Kaisar* motorcycles or pickup trucks when road access to the processing site is available. Shorter distances are usually served by *Kaisar* motorcycles, whereas longer routes rely on pickup trucks. In contrast, water transportation is preferred when the sago forest has river access because land vehicles are often inadequate for hauling heavy logs in swampy or remote areas. *Rakit* and small boats (*pompong*) are commonly used for this purpose (Figure 9). This pattern aligns with the findings of Okazaki (2018), who noted that sago logs from distant forest stands are typically transported by rafts to home-based processing sites. These patterns indicate that transportation strategies in archipelagic environments are strongly influenced by landscape characteristics and accessibility constraints. Transportation choices illustrate how local communities balance efficiency, costs, and environmental conditions. The reliance on water-based and partially manual transport systems suggests relatively lower dependence on mechanized energy inputs compared to fully motorized systems; however, this study does not quantify carbon emissions and therefore does not explicitly evaluate the carbon footprint of each transport mode.

Figure 7. A. Sago threshing tool, B. Sago threshing iron

Figure 8. Sago log transport *rel*

Sago logs are transported either individually or collectively, depending on the transportation mode (Table 2). Typically, 60-90 logs are collected before transport, with each mode differing in work system, wages, and capacity. Modes with higher capacities have lower transport intensity, whereas those with smaller capacities require more frequent trips. *Pompong* transport offers the highest wage at IDR 100,000 per trip with a capacity of 30 logs, whereas *Kaisar* motorcycle transport offers the lowest wage at IDR 25,000 per trip and the smallest capacity, carrying only six logs per trip. These variations reflect the differences in transport efficiency and load capacity among the modes.

Fuel consumption varies across the modes of sago log transport (Table 3). *Pompong* had the highest fuel consumption, at approximately 2.78 L/load, using diesel fuel. This mode is commonly used in Resun Pesisir Village, which serves as a central receiving point for sago logs from various villages in Lingga District. This system can deliver up to 850 logs per trip; therefore, despite the high fuel consumption per trip, the transport capacity efficiency is quite high. Pickup trucks had the second-highest fuel consumption, at 1.07 L/load. Pickups are widely used for medium- to long-distance land routes with adequate road access. Meanwhile, the Kaisar motorcycle had the lowest fuel consumption, at approximately 0.18 L/load. This is in line with its low load capacity (approximately six logs per trip), but it is suitable for short and flexible routes in areas with limited road access. When normalized by load capacity, transport efficiency differs substantially across modes, indicating a trade-off between fuel consumption per trip and volume transported. High-capacity modes, such as pompong, may exhibit higher absolute fuel use but lower energy consumption per unit of transported logs, whereas low-capacity modes, such as motorcycles, require more frequent trips, increasing cumulative energy demand. These findings indicate that transportation energy consumption is influenced by the load capacity, distance traveled, and fuel type. A study on the sustainability of the sago agro-industry supply chain also confirmed that energy use and logistics efficiency are important indicators for assessing the overall performance of the sago system (Yusmiati et al. 2024).

Fuel consumption in sago log transportation is primarily determined by the distance between harvesting sites and processing units. In the Lingga District, transportation is predominantly conducted by water using the *rakit* system. Logs were first rolled to the riverbank and assembled into rafts of 10-20 logs tied together with ropes, with perforations made at the log ends to facilitate binding. This method enables bulk transport with a relatively low energy input, but remains vulnerable to river currents and rope failure. Previous studies have identified limited transportation access as a key constraint in sago supply chains (Trisia et al. 2021), highlighting how infrastructure conditions shape logistical efficiency and operational risks.

Figure 9. Modes of transportation for transporting sago: A. Kaisar motorcycle, B. Pickup, C. *Rakit*, D. *Pompong*

Table 2. Sago log transportation work system and wages

Type of transportation	Work system	Wage (per shipment) (IDR)	Capacity (logs)	Transportation intensity (transportation/day)
Pompong	Group	100,000.00	30	3
Pickup	Group	60,000.00	15	5
Rakit	Group	50,000.00	15	5
Kaisar motorcycle	Individual	25,000.00	6	10

Table 3. Fuel consumption and operational characteristics of sago log transportation systems

Type of transportation	Average fuel consumption (L/transportation)	Route	Fuel type
Pompong	2.78	River	Diesel
Pickup	1.07	Land	Diesel
Kaisar motorcycle	0.18	Land	Gasoline
Rakit	0.00	River	-

Transport typically occurs during high tides in the afternoon or evening. Manual pulling of the *rakit* requires no fuel; however, when currents are strong, a *pompong* (motorized wooden boat) is used to tow the raft, which is capable of carrying 60-100 logs per trip. This practice is consistent with small-scale sago industries elsewhere, where logs measuring approximately 0.9-1.2 m are rafted through rivers or canals to processing facilities (Darma 2018; Jong 2018). The combination of manual and motorized transport reflects adaptive energy use based on environmental conditions. Upon arrival at processing sites, logs are submerged to maintain moisture and starch quality. Although submerged logs can theoretically last 2-3 months, in Lingga, they are typically processed within one month owing to limited storage capacity. Extended soaking may lead to decay and increased starch loss, thereby reducing the yield and quality.

Processed "dirty sago", still mixed with fiber and impurities, must be transported to clean sago mills for washing and filtration. Transportation modes vary according to local geography and infrastructure. Riverine and coastal villages rely on *pompongs*, whereas areas with road access use motorcycles or pickup trucks. In villages such as Musai, Panggak Laut, Pekaka, Keton, and Limbung, water transport dominates because of limited land access. In contrast, Teluk and Merawang use pickup trucks, whereas Nerekeh relies on Kaisar motorcycles. Notably, in Keton, clean sago mills are located within the village, eliminating the need for secondary transportation. This diversified system demonstrates the spatial adaptation of the sago value chain to archipelagic and infrastructural conditions. After being processed into clean sago, the product is transported to the dried sago starch processing center in Kerandin Village using box-shaped canoes with a capacity of up to 100 tons per shipment by sea, which takes approximately two days. The sago products from Lingga District are distributed not only locally but also to other regions, such as Jambi, Palembang, and Cirebon, and even exported to Malaysia, demonstrating that the sago supply chain in Lingga is well connected to regional and international markets. This combination of water and land transportation practices aligns with those of other tropical sago-producing regions. For example, in Sarawak, Malaysia, sago transportation relies on river and canal systems owing to the swampy nature of sago forests (Abbas et al. 2020; Ishak et al. 2021). Infrastructure constraints and long transport distances influence logistics costs and supply chain efficiency (Trisia et al. 2021), thereby shaping the economic viability of sago distribution systems.

The cost of transporting dirty sago from the initial processing site to the clean sago mill is generally borne by buyers, affecting the final selling price, which is higher when costs are passed on to farmers and lower when borne by buyers. Upon arrival, the dirty sago undergoes rewashing and filtering to produce first-grade wet sago for food and industrial use. Transportation is carried out collectively or individually, depending on the mode: *pompong* and pickup trucks typically involve two to four workers, whereas Kaisar motorcycles are operated individually. In collective systems, wages are distributed according to roles such as carrier, stacker, and driver. Field data show that the highest wages are for *pompong* operators at around IDR 400,000 per 60-sack load, while Kaisar motorcycle operators earn around IDR 35,000 per six-sack load. An interesting pattern emerges when considering the capacity and frequency of transportation. *Pompong* have the largest carrying capacity, but their frequency is low, with only 1-2 trips per day. Conversely, *Kaisar* motorcycle vehicles have a smaller capacity but a higher frequency, with up to 10 trips per day. Thus, despite significant differences in transport capacity and frequency, the total gross volume of sago transported is relatively balanced. This phenomenon has also been reported in other sago-producing regions, such as Sarawak (Malaysia) and Papua (Indonesia), where limited transportation infrastructure encourages the use of simple, high-intensity modes of transportation to compensate for their low carrying capacity (Ishak et al. 2021; Trisia et al. 2021). This situation confirms that the sago logistics system remains highly dependent on local adaptation to geographic and socio-economic conditions and requires policy support to improve supply chain efficiency.

Waste utilization

Harvesting also generates residues, such as fronds, leaves, and pith. The pith serves as the primary starch source, and the unusable trunk portion is estimated to be less than 1% of the total biomass (Sasaoka et al. 2014; Wardono et al. 2021). Residues mainly emerged during felling (Figure 10.A) and log splitting (Figure 10.B). Rather than being discarded, these by-products are reutilized; sago hampas is used as ruminant feed despite its high crude fiber and low protein content (Wardono et al. 2021), whereas fronds and bark have potential as eco-friendly construction materials, supporting circular economy initiatives (Rasyid et al. 2020). These practices demonstrate how local knowledge minimizes waste and enhances the ecological and economic efficiency of the sago system.

Figure 10. A. Remaining sago pith following felling, B. Sago pith waste during division

Figure 11. A. Sago fronds as a road material for transporting sago palm, B. Sago leaves as a material for making house roofs

From a biodiversity perspective, the retention and reuse of sago residues contribute to maintaining habitat complexity within sago agroecosystems. In sago forests, portions of biomass, such as discarded pith and decaying trunks, are left in situ, supporting microhabitats for decomposers and associated fauna, including sago beetle larvae (*Rhynchophorus ferrugineus* (A.G.Olivier, 1791)), which play a role in nutrient cycling. This reflects a low-waste management system that aligns with biodiversity-friendly agroecosystem principles, in which biomass recycling supports soil fertility and ecological functions. In addition, fronds and leaves are widely utilized, particularly by women in Lingga. This indicates a gendered division of labor in which women play a key role in post-harvest biomass utilization and value addition. Fronds are used to construct simple wooden tracks (*rel*) for transporting sago logs (Figure 11.A), while leaves serve as roofing material (Figure 11.B). Sago leaves are known for their durability compared to other palm leaves (Flach 1997) and provide superior thermal comfort relative to zinc roofing in tropical climates (Kindangen et al. 2024). In addition to roofing, leaves are used for brushes, baskets, torches, and thatching (Pue et al. 2018; Toyoda 2018).

Analytically, these practices highlight how gendered knowledge systems contribute to the diversification of biomass use and resilience of household economies. Women's involvement in processing and utilizing sago residues extends the value chain beyond primary starch production, linking domestic activities with small-scale economic opportunities, such as the production and sale of sago-leaf roofing panels. Furthermore, milled pith, bark, and frond waste can be utilized as animal feed or as substrates for cultivating oyster mushrooms (*Pleurotus ostreatus* (Jacq.) P.Kumm. and *Lentinus sajor-caju* (Fr.) Fr.) (Taskirawati et al. 2020; Senghie et al. 2021). These diversified uses illustrate a circular biomass system that reduces waste while enhancing livelihood resilience. At the agroecosystem level, such practices may also reduce external input dependence and maintain ecological balance, although these effects were not quantitatively assessed in this study.

Comparative socio-ecological perspectives on sago harvesting and transportation practices in Indonesia

This study moves beyond descriptive comparisons by situating Lingga sago practices within a traditional ecological knowledge (TEK) framework that emphasizes adaptive, place-based resource management. The sago harvesting and transportation system in Lingga demonstrates a distinct configuration of practices compared to other sago-producing regions in Indonesia, including the Meranti Islands, Papua, and Sulawesi. In Meranti, transportation relies more on motorized boats through canal systems, whereas Lingga retains the use of *rakit* (human-powered rafts), although practices such as *narik tual* are also observed (Swastiwi et al. 2023). Rather than framing this difference solely in terms of efficiency, it reflects divergent socio-ecological adaptations shaped by infrastructure availability, hydrological conditions, and energy use strategies. From a TEK perspective, Lingga's reliance on low-mechanization transport represents an energy-minimizing strategy embedded within local ecological constraints, rather than a technological limitation. In contrast, motorized systems in Meranti may increase logistical efficiency but also introduce higher energy inputs and potential environmental pressures on aquatic systems. This highlights how TEK systems encode not only ecological knowledge but also implicit energy-use optimization under specific landscape conditions. Sago processing in Meranti is also more industrialized, reducing reliance on traditional techniques (Yusmiati et al. 2024).

Meanwhile, in Papua, the Marind-Anim people are known for their strong local wisdom in managing sago, including a selective logging system to maintain sustainability (Kadir et al. 2022). However, sago transportation techniques in Papua often rely on direct human labor without the use of wooden rails (*golek*), as found in Lingga. Furthermore, in Papua, sago is more often transported as whole trunks or on simple rafts, but there is no documentation of soaking sago in rivers to maintain starch quality, a practice that is characteristic of Lingga and serves to prevent starch degradation due to oxidation (Nishimura et al. 2018; Irawan et al. 2025).

In Sulawesi, particularly in areas such as Luwu and Morowali, sago harvesting has largely adopted mechanical tools, such as chainsaws. However, it is not accompanied by a systematic peeling and rolling system for sago trunks, as in Lingga (Abbas et al. 2020). Furthermore, sago waste utilization in Sulawesi tends to be limited to animal feed, whereas the Lingga community has developed more diverse uses, including as a roofing material with improved thermal properties (Kindangen et al. 2024), a mushroom medium (Senghie et al. 2021), and even as a supplementary food source through sago beetle larvae (Canti and Muliawan 2025), although its utilization is not yet optimal.

Taken together, these comparisons indicate that the distinctiveness of Lingga lies not in isolated practices but in the integration of harvesting, handling, and transportation techniques into a coherent socio-ecological system. The combination of *golek* (log rolling), *rakit* (rafting), and controlled soaking represents a locally adapted management system that regulates energy use, maintains starch quality, and minimizes biomass loss in peatlands and riverine ecosystems. Theoretically, this study contributes to TEK scholarship by demonstrating how knowledge systems function as operational frameworks that link ecological observation, labor organization, and technological choice. Rather than viewing TEK as static cultural knowledge, the Lingga case illustrates a dynamic system of adaptive co-management in which communities continuously adjust practices in response to environmental constraints and resource conditions. This aligns with the concept of knowledge co-production in community-based resource management (Gómez-Baggethun et al. 2013), in which ecological understanding and practices are mutually reinforcing.

This study also contributes to biodiversity science by showing how TEK-based practices influence the management of sago agroecosystems, particularly in peatland and wetland environments. Selective harvesting based on phenological indicators, combined with controlled extraction intensity and post-harvest handling, may reduce ecological disturbance, maintain stand structure, and support regeneration processes, although these effects were not quantitatively measured in this study. However, the continuation of this TEK system faces structural pressures, including modernization, declining youth participation, and limited institutional recognition. Rather than framing this as a policy recommendation, these findings suggest the need for further analytical integration of TEK into sustainability research, particularly through quantitative assessment of energy efficiency, yield optimization, and ecological impact.

This study is subject to several limitations. The analysis remains primarily qualitative and does not include standardized quantitative indicators, such as energy use per unit biomass, transport efficiency, or ecological regeneration rates. Comparative datasets across regions are also limited, constraining broader generalizations. In addition, gender dimensions were not explored in depth, as harvesting and transportation activities are predominantly performed by men, while women are more involved in post-harvest processing. Future research should integrate quantitative and gender-inclusive approaches to better understand the full socio-ecological dynamics of sago systems.

In conclusion, this study demonstrates that sago management in Lingga is best understood as an integrated traditional ecological knowledge (TEK) system that links phenological observations, labor organization, and adaptive transport strategies within peatland and archipelagic environments. Rather than functioning as isolated practices, the combination of *golek*, *rakit*, and controlled soaking represents a coherent socio-ecological system that regulates harvesting timing, biomass handling, and post-harvest quality under specific environmental constraints. The main theoretical contribution of this study is demonstrating how TEK operates as an applied management framework, guiding resource use and structuring energy efficiency, labor coordination, and decision-making processes. This finding advances TEK scholarship by showing that local knowledge systems function as dynamic and adaptive mechanisms of resource governance rather than static cultural traditions. In terms of biodiversity relevance, the study highlights how TEK-based practices may support the maintenance of sago agroecosystems, particularly in peatland and wetland landscapes. Selective harvesting based on phenological indicators, combined with controlled extraction intensity and adaptive transport systems, has the potential to reduce ecological disturbance and maintain stand productivity, although these effects require further quantitative validation. Overall, the Lingga case underscores the importance of integrating locally grounded knowledge systems into broader sustainability and biodiversity research. In the context of ongoing socio-economic transformation and generational change, the continuity of TEK depends on intergenerational transmission and its capacity to adapt to emerging technological and economic pressures. Future research should focus on quantifying ecological and energy efficiency indicators, as well as examining how TEK can be integrated with context-appropriate innovations without undermining its adaptive functions.

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