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From waste to value through circular economy opportunities in traditional sago processing systems in South Sulawesi, Indonesia

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Abstract. *Tahnur M, Rampisela DA, Rahmadanih R. 2026. From waste to value through circular economy opportunities in traditional sago processing systems in South Sulawesi, Indonesia. Asian J For 10 (1): r100139. https://doi.org/10.13057/asianjfor/r100139.* In the eastern region of Indonesia, sago (*Metroxylon sago*) is a local food that has an important role in supporting food security as well as the livelihood of rural communities. However, traditional sago processing is generally still carried out on a small scale and follows a linear pattern, resulting in large amounts of solid and liquid waste and reflecting inefficient resource utilization. Although the circular economy is increasingly being talked about in the agro-industrial system, empirical evidence for its application to small-scale traditional sago processing is still limited. Using the 9R framework, this study aims to map the stages of traditional sago processing, identify operational obstacles and waste generation points, and trace circular economy pathways that have the potential to be implemented. The research was conducted through an exploratory qualitative case study on a traditional sago processing facility in North Luwu District, South Sulawesi, Indonesia. Data was collected through field observations and semi-structured interviews with key stakeholders involved in the processing process. The results of the study show that the main sources of waste include leaves and fronds, bark, sago waste, liquid waste, and residual starch sediments. The study also found a number of opportunities for circular utilization, such as natural packaging, bio-briquettes, animal feed, mushroom cultivation media, organic fertilizers, biogas production, and sago larval cultivation, although current reuse practices are still limited and informal. Overall, this study presents empirical evidence on waste streams and circular economy prospects in traditional sago processing systems, while offering practical strategies to improve resource efficiency and environmental sustainability in the context of small-scale agro-industry.

Keywords: 9R framework, circular economy, sago processing, sustainability, waste valorization

INTRODUCTION

In Indonesia, sago (*Metroxylon sagu*) is a significant local food commodity, particularly in eastern regions such as Sulawesi, Maluku, and Papua. As it can be processed into various food and non-food products, such as bioethanol, sago-based film for food packaging, and raw material for bioplastic production (Rahawarin 2017; Huang et al. 2018; Ahmad et al. 2020; Arezoo et al. 2020), It serves as a staple source of carbohydrates for local communities and has significant economic potential (Azfaralariff et al. 2020; Maryam et al. 2020). Sago is a strategic crop for bolstering food security in climate-vulnerable areas and maintaining rural livelihoods in forest-based agroindustrial systems due to its exceptional resilience to climate variability and natural disasters (Purbaningsih et al. 2023; Dewayani et al. 2024a, b).

However, sago processing in Indonesia is generally still dominated by small-scale, linear traditional systems. These systems generate large amounts of waste and demonstrate inefficient use of resources. Many processing units still rely on outdated techniques and simple equipment, resulting in low productivity and significant loss of starch that could actually be recovered during the process. Consequently, processors' income is suboptimal, and the competitiveness of sago-based products in both domestic and international markets is declining (Purbaningsih et al. 2023; Dewayani et al. 2024a, b; Nursalam et al. 2025). In this context, the transition towards a circular economy model offers opportunities to enhance environmental sustainability whilst strengthening the economic and social resilience of local communities by utilizing waste that has previously been discarded.

The 9R framework, which has gained prominence in the circular economy discourse, emphasizes the reduction of resource and material consumption throughout the production chain. In the source text, this framework is explained through strategies R0 to R9, which can generally be grouped into three broad orientations: smarter design and use, extending service life, and recovering material value (Potting et al. 2017). Kristianto and Nadapdap (2021) and Ap et al. (2026) describe the circular economy as an economic concept that is integrated with the principles of sustainable development to promote more ethical patterns of production and consumption. Meanwhile, the Ellen MacArthur Foundation positions it as a systemic framework capable of addressing issues of pollution, waste, biodiversity loss, and climate change (MacArthur 2019). Within this framework, waste disposal is not viewed as a final stage, but rather as an opportunity to regenerate the value of resources within the production system, including in sago- based agro-industries.

The application of circular economy principles to traditional sago processing is becoming increasingly important as it can reduce waste generation, improve resource efficiency, and open up new business opportunities through the utilization of agro-industrial by-products. The literature indicates that integrating the circular economy into agri-food supply chains has the potential to strengthen sustainability, reduce waste production, and improve overall resource use performance. In addition to environmental benefits, this approach can also enhance food security, add economic value, and open up new business opportunities in rural areas (Velasco-Muñoz et al. 2021; Islam et al. 2024; Susanto et al. 2024). Nevertheless, practical studies on how these principles are applied in small-scale traditional sago processing systems remain relatively limited.

The transformation of sago processing towards a circular economy model also requires institutional support, stronger collaboration, product diversification, and the modernization of processing technologies. With such support, the sago processing system has the potential to evolve into a more resilient, efficient, and inclusive agro-industry, particularly in rural and forest- based livelihood contexts (Timisela et al. 2021; Yuntafau et al. 2022; Dewayani et al. 2024a, b). Therefore, the development of circular economy strategies appropriate to the local context requires a detailed understanding of waste streams, sources of inefficiency, and realistic pathways for utilization within current processing practices.

Based on these considerations, this study aims to generate contextual empirical insights into the potential for waste utilization from traditional sago processing. Specifically, this study aims to: identify the stages of traditional sago processing; analyze key operational issues and waste generation points at each stage; and map and screen circular economy options qualitatively using the 9R framework. Through a qualitative case study of a small-scale conventional processing unit, this study seeks to provide a basis for the development of a sago processing system that is more sustainable and more efficient in its use of resources.

MATERIALS AND METHODS

Study area and research design

This study employs a single qualitative case study approach of an exploratory nature, focusing on a small-scale traditional sago processing unit in North Luwu District, South Sulawesi, Indonesia. The case study approach, waste generation patterns, and waste management practices in real-world settings. Unlike quantitative surveys, qualitative case studies allow researchers to examine the complex relationships between technological, social, economic, and environmental factors that shape production systems within traditional agro-industries.

The selection of the location was based on its relevance as a sago-producing region in South Sulawesi. In North Luwu District (Figure 1), sago processing is generally community-based, relying on local labour and traditional procedures. The selected unit reflects operational characteristics commonly found in small-scale sago processing in the region, such as manual harvesting, simple mechanical grating, and on-site starch extraction. For this reason, this unit is considered suitable as a case study to explore the potential for circular economy applications.

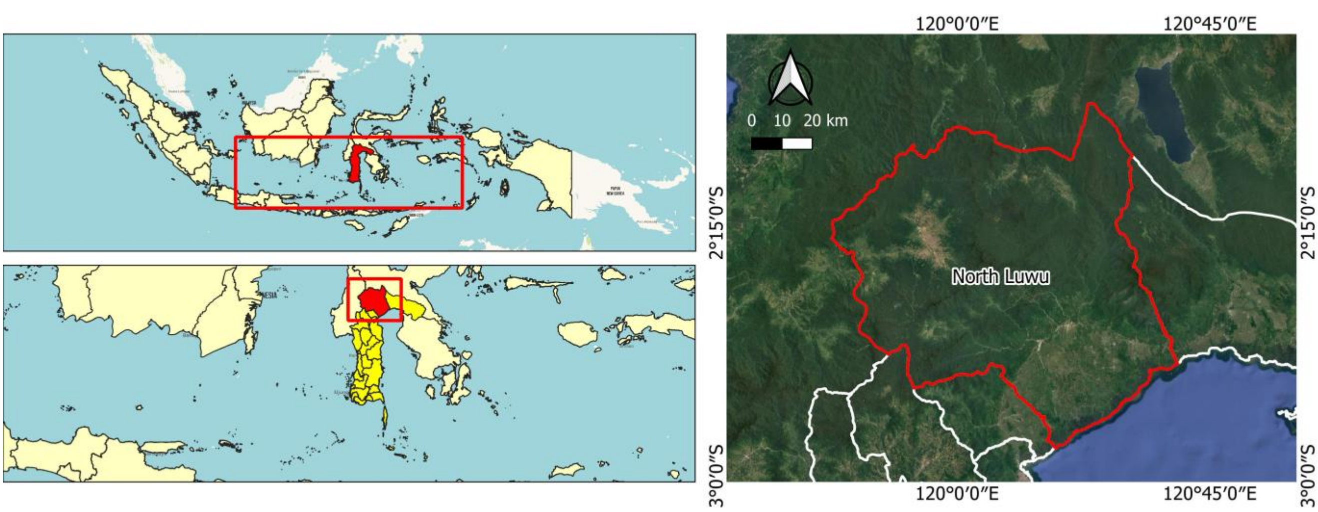

Figure 1. Research location map in North Luwu District, South Sulawesi, Indonesia

The research comprised two stages of data collection. In the first stage, data was obtained from a single processing unit involving the sago owner, processors/ managers, and workers, to map the stages of the sago processing process. In the second stage, interviews were conducted with four processors/managers to explore in greater depth the types of waste produced and their current forms of utilization. Data from the second stage were analyzed using NVivo 12 to map the relationships between informants' knowledge, the types of waste, and their current forms of utilization. In line with the nature of qualitative case studies, the orientation of this research is analytical generalization, not statistical generalization. Consequently, the research results are intended to produce process maps and conceptual insights relevant to similar contexts, rather than to produce numerical estimates representing the entire sago processing system in Indonesia.

Data collection

Data collection was carried out using two main techniques: semi-structured interviews and direct field observation. These two techniques were chosen to enable the researcher to triangulate the informants' accounts with the practices actually observed on site. Interviews in the first phase included key actors in sago processing (Table 1): the sago owner (n = 1), the processor/manager (n = 1), and workers (n = 2). The selection was carried out purposively to obtain participants who were knowledgeable and directly involved in various stages of the processing chain, from tree selection to the production of wet sago starch. In the second stage, four processors were interviewed to obtain more detailed information regarding the types of waste, existing utilization practices, and their perceptions of the value of the waste. Interview topics covered the stages of the process, the techniques used at each stage, the types of waste generated, and current waste management and utilization practices. Each interview lasted approximately 45-90 minutes and was documented through audio recordings and field notes, with participants' consent.

In addition to interviews, the entire sago processing procedure was also documented through non-participant field observations, ranging from raw material selection and harvesting to grating, starch extraction, sedimentation, and packaging. The researchers also observed the physical conditions around the site, including the accumulation of residues, the flow of li quid waste, and waste disposal practices. Observations were carried out during several visits in August and October 2022. Repeated visits helped to strengthen the reliability of the findings through repeated observations and methodological triangulation.

Previous research shows that the balance of waste generated from the sago processing process can be seen through the approach in Table 2. Previous research shows that the estimated starch and waste produced from the sago stem processing process shows a considerable potential for waste utilization.

The data collected was then analyzed to identify potential applications of the circular economy, specifically the utilization of sago processing waste into value-added products such as animal feed, biomass energy, and organic fertilizer. The 9R framework was used as an analytical lens to categorize waste streams and potential utilization alternatives (Table 3). The qualitative analysis stages included: reviewing interview transcripts and observations; identifying key themes related to process stages and waste generation points; classifying observed waste streams and existing utilization practices; and mapping these findings into the R0-R9 categories. The final stage involves a qualitative screening of circular economy options based on considerations of economic viability, environmental benefits, and social implications, without detailed quantitative measurements of waste volumes, cost structures, or market prices at the study site (Donner et al. 2020; Razak et al. 2022; Islam et al. 2024).

Table 1. Actors' definitions and functions in the sago processing value chain

Category actor's	Definition	Main role	Number of informants
Sago of Owner	An individual who legally owns sago palms on privately owned land.	Agreeing on transactions with the sago processor and deriving income from the sale of sago palms.	1
Manager/ Processor	The party responsible for managing all sago processing activities until the wet sago starch is ready for sale.	Selecting trees for harvesting, cutting the sago trunks, organizing and participating in processing (including operating the sieve machine), negotiating with sago owners, and reaching out to buyers.	1
Employee/Laborer	Workers who assist with the operational aspects of processing.	Transporting trunks, splitting trunks for grating, moving grated material for extraction, cleaning residues, and packaging wet starch.	2

Table 2. Estimated mass balance of products and sago stem waste

Components	Estimated percentage of sago trunk weight	Remarks	Citations
Sago starch (product)	14-20%	Dry starch/flour	(Bantacut and Indriyani 2022; Susanto et al. 2024)
Bark trunk	17-26%	Lignocellulose solid waste	(Bantacut and Indriyani 2022)
Hampas/ Pulp pith	49-60%	Fibrous solid waste (pulp)	(Bantacut and Indriyani 2022)
Liquid waste	20%	Waste water, such as carbohydrates	(Bantacut and Indriyani 2022)

Table 3. The 9R framework

9R framework	Description
R0-Refuse	Avoiding unnecessary products or excessive features
R1-Rethink	Intensify product utilization
R2-Reduce	Improving efficiency by using fewer resources
R3-Reuse	Reusing products that still function as intended
R4-Repair	Repair products so they can be used again
R5-Refurbish	Restoring and upgrading old products
R6-Remanufacture	Using discarded product parts for new products with similar functions
R7-Repurpose	Using discarded product or its parts in a new product with a different function
R8-Recycle	Processing materials to create new materials of equivalent or lower quality
R9-Recover	Recovering energy from materials

Source: Adapted from Potting et al. (2017)

RESULTS AND DISCUSSION

Characteristics of the sago processing system

Observations indicate that the sago processing process at the study site comprises a relatively consistent series of stages, namely tree selection, harvesting, trunk cutting, trunk splitting, pith grating, starch extraction, sedimentation, and packaging (Table 4). In some locations, landowners are directly involved in harvesting, whilst in others these activities are handled by specialized harvesting groups. Each stage generates both solid and liquid waste streams, thereby opening up some potential points for circular economy interventions along the processing chain (Susanto et al. 2024).

Sago processing also requires large quantities of water, particularly during the grating, extraction, and starch sedimentation stages. This water requirement influences the siting of processing facilities, which are generally located near water sources. The main end product is wet sago starch, whilst by-products include solid waste such as leaves and sheaths, bark, and sago pulp, as well as liquid waste from the starch extraction process. If managed appropriately, all these by-products have the potential to be utilized within a circular economy framework.

Problems and opportunities for development

The traditional sago processing system, as observed in this study, reveals issues at almost every stage of production. Observations and interviews indicate that a significant amount of organic waste is generated during processing, yet most of it remains unmanaged or underutilized. This situation is linked to technological limitations, weak market demand for by-products, and the absence of a structured waste management system at processing sites.

In addition, sago processing requires a large amount of water, which is different from many other types of agricultural product processing. Most of the water is discharged directly into rivers or other water bodies around the site, thus raising the problem of environmental pollution. Thus, the problem of waste in sago processing does not only concern solid residues, but is also closely related to liquid waste management and its impact on the quality of the surrounding environment.

At the harvesting stage, leaves and sheaths are almost always produced, but are rarely utilized and are generally left to accumulate around the site. Uses observed in the field are limited and informal, for example, for simple roofing. At the grating stage, two main types of solid waste emerge: sago bark (17-26%) and sago pith/ pulp (49-60%). Both of these residues are generally discarded or left to decompose around the site. Informants also confirmed that simple grating equipment limits starch recovery, meaning that some starch is discarded along with the pulp. This indicates technological inefficiency that directly contributes to material loss and increased waste generation

During the extraction stage, the use of a very large volume of water produces liquid waste that still contains residual starch (20%). At the observed site, this liquid waste is discharged directly onto land or into watercourses without further treatment, indicating the absence of liquid waste management infrastructure in traditional small-scale systems. A similar pattern occurs during the sedimentation stage, where residual starch remains trapped in the sediment and is subsequently discharged into the environment. As well as representing a loss of resources that could potentially be recovered, this practice also increases the risk of water pollution

Table 4. Sago procedure processing

Processing stage	Objective	Description
Selection of sago palms	Identifying a mature tree with high starch content	Selection is carried out using visual indicators such as stem size, height, the presence of 3-4 crown leaves, and the absence of flowering
Harvest	Harvesting sago trunks for processing into starch	The selected sago palms are felled by a team of 5-6 workers.
Cutting the trunk into logs	To facilitate transport to the processing site	Trunks are cut into sections approximately 50-60 cm long.
Splitting the logs	Facilitates access to the pith	Each log section is split into 4-5 pieces
Grating the pith	Separating the starchy pith from the bark	A simple mechanical grater is used to shred the pith and separate it from the bark.
Starch extraction	Separating the starch from fibrous pulp	The pulp is mixed with water and filtered; the water flow carries away the starch, whilst the pulp is retained.
Starch sedimentation	Precipitating starch from the remaining impurities	The starch-water mixture is left to stand until the starch settles.
Packaging	Facilitating market distribution	Wet sago starch is packed in sacks for direct sale or via intermediaries.

The number of sago stalks processed by the processing unit in one month is 15 stalks with an average weight of 1,500 kg/stalk. Based on the assumption of the sago waste balance in Table 5, the total waste produced reached 19,350 kg or 1,935 tons every month, with waste criteria in the form of skin, pulp, and liquid waste. This potential is an opportunity to utilize waste through circular economy interventions.

The findings from source triangulation indicate that waste is an integral component of the production activities carried out by the informants (Figure 2). Waste is generated continuously and in significant quantities, primarily in the form of fronds, leaves, pulp, and bark. The utilization mentioned remains limited; for example, leaves are used for roofing and stems for firewood, whilst liquid waste is generally disposed of and not utilized. Most informants view waste as something that has not been optimally utilized and remains a source of environmental problems (Table 6). The accumulation of organic residues is also associated with unpleasant odors, water pollution, and potential health risks. In other literature, large-scale accumulation of organic waste is also known to reduce the productivity of the surrounding agricultural land (Hartini et al. 2021).

Potential application of circular economy concepts in sago processing

The fundamental principle of the circular economy is to minimize negative outputs in the form of waste by regenerating materials into new products or functions of value. In the agro-industrial sector, the application of this principle is considered crucial as it can enhance environmental resilience, strengthen social welfare, mitigate environmental degradation, and generate value-added products aligned with green economic growth (Lakshmi et al. 2020). In the context of traditional sago processing, this framework is useful for identifying practical ways to transform process residues into resources that offer both economic and ecological benefits.

Table 6. Problems identified in traditional sago processing

Processing stage	Key problems
Harvesting	Leaves and fronds are left unused and pile up around the site.
Grating	Produces bark and pulp that is often discarded; traditional tools result in low starch recovery.
Starch extraction	Starch-rich liquid waste is discharged directly into the environment.
Starch sedimentation	Residual starch remains on the sedimentary medium and is discarded untreated without processing

Table 5. Results of processing sago bulk/month

Components	Composition (%)	Volume (kg)/btg	Volume (kg/mo)	Waste potential (kg)	Output (%)
Wet *pati*	14	210	3,150	-	14
Bark trunk	17	255	3,825	3,825	86
Hampas/pulp	49	735	11,025	11,025	-
Liquid waste	20	300	4,500	4,500	-
	100	1,500	22,500	19,350	100

Note: -: Absent

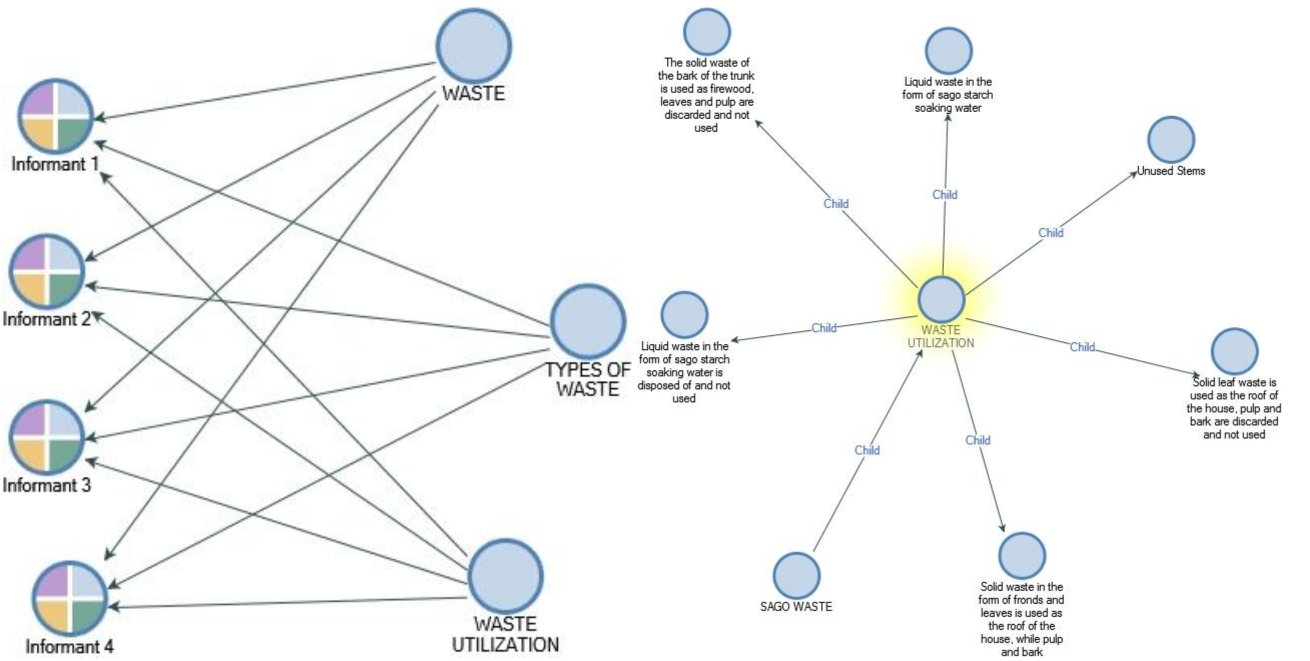

Figure 2. Source triangulation using the inter-code relationship and waste utilization

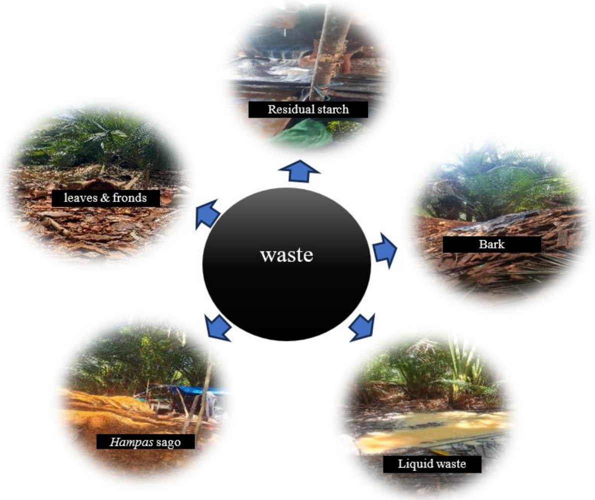

Figure 3. Sago processing waste

Based on field observations, stakeholder views and relevant literature, this study identifies that solid waste in the form of leaves and fronds, bark and sago pulp, as well as liquid waste from starch extraction, opens up several potential pathways for the application of the circular economy (Table 7). A small number of reuse practices have been identified in the field, but most other options remain potential and require technological, organizational, and market access support.

Reusing of leaves and fronds (R7 - Repurpose)

Harvested leaves and fronds constitute a substantial biomass resource. Although there is still little systematic application, field observations show that these materials are occasionally repurposed for basic roofing materials. Woven sago leaves are also utilized as natural food product packaging and for roof construction in various rural Indonesian environments. Reusing leaves and fronds can help cut down on trash production and lessen reliance on plastic packaging.

Sago leaves and fronds constitute a significant amount of biomass in traditional sago processing systems (Figure 3). Field observations indicate that these materials are sometimes used for simple roofing, whilst other literature suggests that sago leaves can also serve as natural packaging for food products. In a more consistent mapping against Table 7, this practice aligns most closely with R7 as the waste material is reused for a new function. Economically, the use of leaves and fronds can reduce packaging costs and create employment opportunities for local artisans; socially, this practice supports the preservation of traditional skills; and environmentally, it can reduce reliance on plastic packaging (Trisia et al. 2018; Masdjudi et al. 2019).

Conversion of bark into bio-briquettes (R9 - Recovery)

A similarly rich residue is sago bark trunk that is still underutilized. One of the promising paths is the processing into bio-briquettes as an alternative energy source. The potential waste of 3,825 kg or 17% of the total composition of processed sago stems showed that this material has enough potential to be used as raw material for bio-briquettes. Although this practice has not been observed at the study site, previous studies have shown that sago peel has characteristics that are suitable for the manufacture of biomass briquettes and has the potential to be an alternative fuel for households and small businesses (Puluhulawa et al. 2023). This option is in line with the R9 principle since it is based on the recovery of energy from waste. Bio-briquettes can be an additional source of income where processing technology and market access exist, while reducing waste accumulation and pressure on conventional firewood.

Recycling of sago hampas *(R8 - Recycle)*

Sago *hampas* is one of the most promising by- product for circular utilization. Most of the *hampas* residues at the study site were discarded or left for decomposition, demonstrating an untapped potential for resource recovery. The study identified several potential pathways to recycle *hampas* into value-added products. The estimated potential waste generated waste in the processing process is 11.025 kg/month or 11,025 tons/month, and is the largest waste produced.

One way is to use the *hampas* for animal feed. It has been scientifically proven that sago hampas contains fiber and residual starch and is suitable to be used as supplementary feed for ruminants (Wardono et al. 2021). Utilizing *hampas* as feed can reduce feed costs for livestock farmers and create market opportunities for processors.

Another pathway is using *hampas* as a substrate for mushroom cultivation. Mushroom production requires lignocellulosic materials, and sago *hampas* can serve as a suitable medium. Studies have shown that mushroom cultivation on agricultural residues can generate significant economic returns and reduce waste volumes (Hendrawani and Hulyadi et al. 2023). This option could create new agribusiness opportunities for rural communities.

Additionally, sago *hampas* can be regenerated into liquid fertilizer or organic compost. By lowering dependency on chemical fertilizers and enhancing soil health, the production of organic fertilizer can promote sustainable agriculture. Similar waste-to-compost programs have been implemented in various agro-industrial contexts, providing both financial and environmental advantages (Istikowati and Sunardi 2022).

Using *hampas* as a substrate for the growth of sago larvae is one very creative approach. In many parts of Indonesia, sago larvae are acknowledged as a high-protein food source. Using *hampas* to cultivate larvae results in a closed-loop system where trash is transformed into a profitable food product. Because larvae have a high market value and can help ensure local protein security, this alternative has significant economic potential (Yeheskiel et al. 2023). This option is in line with the R8 principle because the waste is reused without charging its shape as a medium for mushroom cultivation, cultivating larvae media, animal feed, and compost raw materials.

Table 7. Circular economy alternatives in sago processing

Identified issues	Circular solution	9R strategy	Circular economy benefit
Leaves & fronds are not utilized	Used as roofing and traditional packaging	R7 - Repurpose	Saves on packaging cost, reduces plastic waste, and creates job opportunities in weaving activities.
Unused bark	Processed into bio-briquettes	R9 - Recovery	Providing renewable fuel, reducing pollution, and increasing income.
Sago *Hampas* are not utilized	Used as animal feed	R8 - Recycle	Reducing feed cost, opening up new markets.
	Used as a substrate for mushroom cultivation	R8 - Recycle	Increasing income whilst reducing waste.
	Processed into a compost or liquid fertilizer	R8 - Recycle	Increases economic value and supports sustainable agriculture.
	Used a Medium for sago larvae farming	R8 - Recycle	Produces high-value protein sources and creates new business opportunities in rural areas.
Inefficient starch extraction	Modernization of processing equipment	R1 - Rethink	Increased starch yield and reducing waste at sources.
Wastewater is not treated	Processed into biogas	R9 - Recovery	Provides renewable energy and reduces water pollution
Starch Residue sediment	Processed into liquid organic fertilizer	R8 - Recycle	Increases income and supports environmentally friendly farming practices.

Modernization of processing equipment (R1 - Rethink)

Stakeholders assess that one of the main constraints in traditional sago processing is the low efficiency of starch extraction. Consequently, the modernization of grating and extraction equipment is viewed as a key upstream intervention to improve production efficiency and reduce waste at source. By rethink (R1), better equipment, more starch can be recovered from the raw material, less starch is lost with the pulp or liquid waste, and the processors' potential income can increase. However, this option requires financial investment and technical capacity that may be difficult for small-scale processors to meet without institutional support or co-financing schemes.

Recovery of wastewater through biogas production (R9 - Recovery)

Liquid waste from starch extraction is rich in organic matter, making it theoretically suitable for anaerobic digestion and biogas production. The liquid waste generated is estimated to be 4.500 kg/month or 20% of the total waste generated in sago processing. With a large amount of waste, this material has the potential to be used as a raw matrial biogas. Although biogas systems have not yet been observed in the units studied, previous research indicates that sago wastewater has the potential to be processed into biogas and support energy self-sufficiency within more closed processing systems (Bantacut and Indriyani 2022) .If implemented, this approach could not only reduce water pollution and emissions from uncontrolled organic waste decomposition but also provide an alternative energy source for households or small businesses. The main challenges relate to the need for initial investment, technical knowledge, and the ability to maintain the facilities.

Utilization of residual starch sediment (R8 - Recycle)

The residual starch sediment left after the settling stage is also a resource that is currently largely wasted. This material can be processed into liquid organic fertilizer, in line with the R8 strategy, which aims to return materials to the productive system in a new form. In practical terms, this option offers two benefits simultaneously: a reduction in waste load and the generation of economic value through agricultural support products. Although this study did not quantitatively measure the sediment content or its economic viability, the exploratory results indicate that this pathway is relevant for further development within the context of traditional sago processing.

Overall, the circular economy options identified in this study were screened qualitatively rather than quantitatively. These options were considered based on economic benefits, environmental benefits, and social implications, with the awareness that the single-case study design does not provide detailed measurements of waste volumes, implementation costs, or market prices. Nevertheless, within the context of the small-scale traditional processing systems examined, the transition from a linear to a circular model appears to be a sensible pathway to support the development of a more sustainable sago agro-industry.

In conclusion, this study demonstrates that the circular economy concept can be applied to traditional sago processing systems through the utilization of solid and liquid waste generated during the production process, coupled with improved processing efficiency. Key stages identified include tree selection, harvesting, grating, starch extraction, sedimentation, and packaging. At these stages, waste streams in the form of leaves and fronds, bark, sago husks, liquid waste, and residual starch sediment were observed. Currently, these wastes are generally not utilized optimally and are often disposed of into the environment, thereby limiting opportunities for value addition whilst causing pollution burdens. Based on field observations, stakeholder perspectives, and supporting literature, this study identifies several waste valorization pathways within the 9R framework, including the use of leaves and fronds for packaging and roofing, the processing of bark into bio-briquettes, the recycling of sago pulp into animal feed, compost, fertilizer, mushroom cultivation media, and sago larva cultivation media, as well as the treatment of liquid waste into biogas and residual starch sediment into liquid organic fertilizer. This study also confirms that low starch extraction efficiency is a major constraint, suggesting that modernizing processing equipment could be a key strategy for increasing starch yield and reducing material loss. Overall, the application of the circular economy in sago processing presents opportunities to improve resource efficiency, reduce environmental pollution, and generate greater economic value for rural communities. However, as it is based on a single qualitative case study, these findings should be understood as contextual exploratory insights rather than universal generalizations. Further research is still required to assess waste volumes, economic viability, and market potential quantitatively.

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