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REVITALIZATION OF THE SAGO FOREST ECOSYSTEM THROUGH PROTEIN ANALYSIS OF SAGO WORMS (*RHYNCHOPHORUS FERRUGINEUS*) AND CHEMICAL CHARACTERISTICS OF SAGO STARCH (*METROXYLON SAGU*) AS A NUTRITIONAL SOURCE FOR ACHIEVING SUSTAINABLE DEVELOPMENT GOALS (SDGS).

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Abstract

This research aims to analyze the revitalization of the sago forest ecosystem, the protein content of sago worms (*Rhynchophorus ferrugineus*), and the physicochemical characteristics of sago starch. The research methods involve literature review and protein analysis using UV-Vis spectrophotometry, SDS-PAGE, and the Kjeldahl method. The results indicate the need for sago forest revitalization to enhance the productivity and sustainability of sago raw materials. Protein analysis of sago worms shows that salting with a 10% concentration without heating is the most recommended preservation method. Amylose content analysis of sago starch shows that PSIA has an amylose content of 27.22%, and acid hydrolysis can reduce amylose content while increasing the crystallinity degree of the starch. This research supports the achievement of Sustainable Development Goals (SDGs) in terms of food security, poverty alleviation, and environmental conservation.

Keywords: Sago forest revitalization, Sago worm protein, Sago starch characteristics, SDGs.

1. Introduction

The sago palm (*Metroxylon sagu*) is an indigenous plant of Indonesia, renowned for its high genetic diversity and predominantly found in the eastern regions of the country. Major cultivation centers in Indonesia include Papua, West Papua, Maluku, North Maluku, Riau, Sulawesi, and Kalimantan. Despite its prevalence, accurate data on the area of sago plantations, whether cultivated or wild, remains insufficient [1]. Sago forests play a vital role in the ecosystem and the lives of communities in various regions of Indonesia, including Sorong in Southwest Papua. These forests provide staple food, economic resources, and contribute to environmental balance [2]. However, sago forests are currently facing numerous issues threatening their sustainability, such as land conversion, deforestation, and forest degradation.

The conversion of sago forest land into oil palm plantations and mining activities has resulted in the loss of crucial sago ecosystems. Additionally, uncontrolled deforestation reduces habitats for endemic flora and fauna and degrades the quality of the local environment. In Sorong, these issues are exacerbated by a lack of understanding and awareness among the community about the importance of preserving sago forests. Unsustainable management and excessive exploitation without adequate reforestation efforts further worsen the condition of sago forests, diminishing their potential as a food and economic resource.

Sago worms (*Rhynchophorus ferrugineus*) are nutrient-rich and can serve as an alternative local food for communities. A study showed that children aged 1-5 years in Southeast Sulawesi who consumed sago worms exhibited increased protein levels compared to those who did not consume them. Besides being rich in protein, sago worms also contain essential minerals such as calcium and magnesium, which are vital for strengthening bones and teeth [3, 4]. Sago starch contains amylose and amylopectin. Amylose has a linear structure that is easily digested by amylase enzymes, while amylopectin has a branched structure that is more resistant to digestion. As a source of complex carbohydrates, sago starch provides essential energy for daily activities. Its low glycemic index helps control blood sugar levels, making it a good choice for diabetics.

The fiber content in sago starch also benefits digestive health by facilitating bowel movements and acting as a prebiotic. Furthermore, sago starch can aid in weight management by providing a longer-lasting feeling of fullness. Being gluten-free, sago starch is suitable for individuals with celiac disease or gluten sensitivity and can be used as a substitute for wheat flour. In the food industry, sago starch is often used as a thickener in soups, sauces, and puddings, as well as a binding agent in products like meatballs and nuggets. In Indonesia, sago starch is also used in traditional foods such as papeda and sago lempeng.

Despite its great potential as a food source, several challenges exist in the processing and marketing of sago. For instance, the Bina Sagu partner business group experiences difficulties in producing high-quality sago starch because the extraction process is still done manually. The resulting sago starch has high water content, a light brown color, is prone to mold, and has a relatively low price. Additionally, negative perceptions of sago products and lack of effective promotion are barriers to increasing consumer interest. This research aims to uncover alternative nutrient-rich food sources and support sustainable development goals

(SDGs) related to food security, poverty alleviation, and environmental conservation. By analyzing the protein content of sago worms and the properties of sago starch, this study seeks to provide a foundation for future planning and management strategies. It addresses the challenges in sago processing and marketing, ultimately aiming to support the sustainable development of sago palm products [5, 6].

2. Methods

This research began with a literature review, conducted using the Scopus and Google Scholar databases. Keywords included "sago forest ecosystem," "sago forest," "sago worm," "sago starch," "utilization of sago worm," "sago starch characteristics," "SDGs achievement," and "local nutrition." Detailed information for the bibliometric analysis is explained elsewhere [7, 8]. The sources comprised national and international journals as well as open-access materials. The literature review was performed as an unsystematic narrative review, focusing on synthesizing information from articles published in the last 10 years.

The process involved collecting data, reading, noting, and comparing relevant literature to gain a deep understanding and draw conclusions related to the research topic. After gathering secondary data from journals, scientific articles, and literature reviews on sago worms and sago starch, the abstracts of each study were read. The aim was to ensure that the issues discussed in each study aligned with the research objectives. Protein analysis methods such as Kjeldahl, Spectrophotometry, and SDS-PAGE were reviewed, along with the physicochemical characteristics of sago starch using acid hydrolysis. This step ensured that the selected studies were relevant and contributed to the research goals.

3. Result and Discussion

3.1. Bibliometric analysis for literature survey

Bibliometric is one of the effective methods for understanding research trends [9]. The results showed that the research on sago started from long time ago, and increasing every year. Figure 1 displayed a data analysis of document results, totaling 2,342 documents. The data was organized by year, ranging from 1837 to 2024.

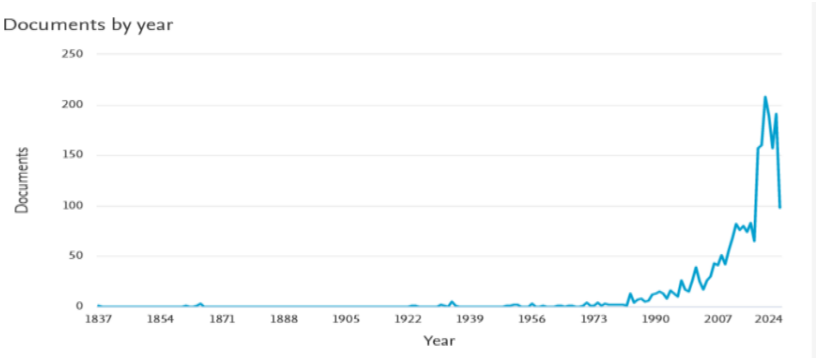

Fig. 1. Literature survey based on Scopus database using keyword "sago" taken on June 2024.

3.2. Revitalization of sago forests

Sago forests, which are natural forests with waterlogged and muddy conditions and difficult access, often face challenges in inventorying their potential. Data published by various agencies often varied, indicating the complexity in assessing the potential of these sago natural resources.

To address these challenges, integrated planning and the utilization of advanced technology were needed to more accurately identify and inventory the resources [10]. Sago requires about 10-12 years to complete its life cycle from seed to seed again under optimal ecological conditions. The growth phases of sago include (a) the rosette phase, which takes about 45 months, (b) the trunk formation phase, lasting for 54 months, (c) the flowering phase, reaching 12 months, (d) the fruit maturation phase, taking about 24 months. The total time required from start to finish was approximately 10-12 years [11]. For more details, please refer to Fig. 2 regarding the sago life cycle.

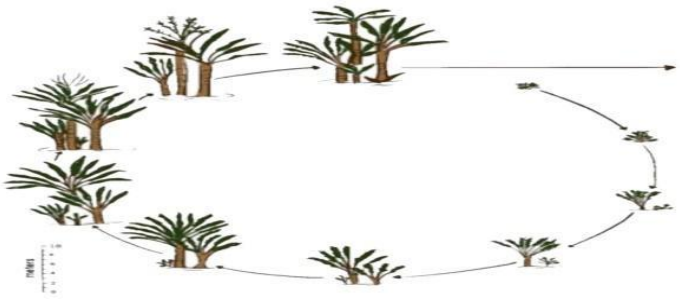

Fig. 2. Sago life cycle [12].

Based on several expert opinions, the life cycle of the sago plant consisted of six growth stages, namely (a) sprout, (b) sucker, (c) young palm, (d) not ready for harvest, (e) ready for harvest, and (f) overripe for harvest. [13]. The growth and development of plants are significantly influenced by genetic factors and environmental factors. Sago exhibited extraordinary genetic diversity due to its widespread distribution across the Indonesian archipelago. Each sago-producing region had different accessions or varieties. Sago's ability to adapt to various growing environments was very broad. This was greatly influenced by the physiological processes occurring in sago plants as they responded to environmental influences.

The high or low starch production in the sago trunk was highly dependent on the physiological processes within the sago plant itself [14]. Meeting the long-term demand for sago could not rely solely on natural sago forests or cultivation with currently low productivity. For example, starch production from cultivated sago in the Meranti Islands only reached 10 tons per hectare per year [15], far below the production achieved in South Sorong 34.59 tons/ha/year and Sarawak, Malaysia 23 tons/ha/year [16, 17].

To increase productivity and ensure the sustainability of raw materials, more optimal development of sago through the revitalization of sago forests and intensification is needed. Revitalization of sago forests also involved monitoring and evaluating the progress and impact of restoration activities undertaken.

Scientific analysis of the success of revitalization could include the recovery of biodiversity, increased availability of local food resources such as sago, and contributions to achieving the SDGs, especially those related to food security, environmental sustainability, and community welfare.

3.3. Protein analysis of sago worms (Rhynchophorus ferrugineus)

Protein analysis of sago worms (Rhynchophorus ferrugineus) was conducted using spectrophotometry and SDS-PAGE after the drying process, both with and without salt. A simple UV-Vis spectrophotometry method specific to proteins did not detect nitrogen from non-protein components and was faster to perform compared to other methods. Detailed information regarding UV-Vis is reported elsewhere [18]. SDS-PAGE was a method for separating polypeptide chains in proteins based on their ability to move in an electric current, which is a function of the length of the polypeptide chain or its molecular weight. This was achieved by adding the detergent SDS and applying heat to disrupt the three-dimensional structure of the protein by breaking disulfide bonds, which are then reduced to sulfhydryl groups. SDS formed complexes with proteins, and these complexes carried a negative charge due to the anionic groups of SDS [19].

The UV-Vis spectrophotometry method specific to proteins was a simple and rapid technique for measuring the amount of protein in a sample solution. This technique works on the principle that each chemical component can absorb or reflect light at specific wavelengths in the UV-Vis spectrum. This method was effective in detecting proteins because proteins tended to absorb light at certain wavelengths [20]. On the other hand, SDS-PAGE was a method for separating polypeptide chains in proteins based on their molecular weight.

This process involves the addition of the detergent SDS (Sodium Dodecyl Sulfate), which results in a protein-SDS complex with a negative charge due to the anionic groups of SDS. Heating was used to disrupt the three-dimensional structure of the protein and reduce disulfide bonds, allowing the protein to be separated based on its molecular weight in gel electrophoresis. This method was a standard technique in protein analysis to understand the composition and characteristics of complex proteins [21]. The total protein results in sago worms are shown in Table 1.

Table 1. Total protein content in dried sago worms using salt and without salt.

Sample	Absorbance	Total Protein (µg/µL)
Control	0.4026	4.93
GK	0.8365	2.31
G	0.6001	3.09
K	0.7391	2.44

Note : GK: Drying using an oven at 50 °C *for 1 hour with* 10% *salting; G:* 10% *salting for* 1 *hour; K: Drying using an oven at* 50 °C *for* 1 *hour*

The spectrophotometer results for sago worms in Table 1 showed that the control had higher protein content (4.93 µg/µl) compared to sago worms that had undergone salting for 1 hour (3.09 µg/µl) and the lowest protein content after 10% salting and drying for 1 hour at 50°C (2.31 µg/µl). After drying at 50°C and salting

with a 10% concentration (w/w), the number of protein bands in sago worms decreased from 26 to 19 bands. In the sample that was only dried in an oven at the same temperature for 1 hour without using salt, the number of protein bands decreased from 26 to 21 bands.

Meanwhile, in the sample that was only salted with a 10% concentration (w/w) for 1 hour without drying, the number of protein bands did not decrease significantly, remaining at 24 bands. The salting treatment with a 10% concentration (w/w) indicated that the combination with drying using an oven at 50°C has the most significant effect on the denaturation of sago worm proteins. The analysis results showed that to preserve sago worms, it was recommended to use salting with a 10% concentration (w/w) for 1 hour without heating, as this condition did not significantly reduce the number of protein bands.

Proteins underwent denaturation or chemical structure changes due to the influence of heating, such as the breaking of bonds within protein molecules, especially at temperatures of 50–80°C. The salting process caused proteins to become less soluble due to the formation of disulfide cross-links, which reduces protein solubility. The appropriate salt concentration, for example, 15%, could help bind proteins and prevent protein damage during the salting process. The higher the salt concentration, the greater the likelihood of reducing the protein content in the sample.

3.4. Protein Analysis in Sago Worms Using the Kjeldahl Method

The Kjeldahl method was not used to measure protein directly. The use of sulfuric acid at high temperatures could be hazardous, and this method requires a considerable amount of time. A drawback of the Kjeldahl method was that it could not differentiate between various nitrogen-containing compounds, such as purines, pyrimidines, vitamins, amino acids, and the like, as all were measured as total nitrogen [22]. Research results showed that the protein content in sago worms on thorny stems was 11.8652%, while in sago worms without thorns, the protein content was 10.06988%.

A study conducted by Widiastuti & Kisan in East Halmahera Regency, North Maluku, found that the total protein content of sago worms was 4.0575%. Several factors affecting the quality of protein in sago worms include moisture, temperature, and the provision of food containing nutrients such as nitrogen (N), hydrogen (H), oxygen (O), and carbon (C).

3.5. Characteristics of Sago starch, Amylose content analysis

Amylose Content Analysis in Starch Following AOAC Method [23] First, 100 mg of starch sample was placed in a 50 mL test tube. Then, 1 mL of 95% ethanol and 9 mL of 1 M NaOH solution were added, followed by vortexing to mix. The mixture was heated in a boiling water bath for 10 minutes, then diluted to a volume of 100 mL. Next, 5 mL of the sample solution was transferred to a 100 mL volumetric flask and 1 mL of 1 N acetic acid solution and 2 mL of 0.01 N iodine solution were added. Distilled water was added up to the mark. The solution is heated in a water bath at 30°C for 20 minutes.

The intensity of the blue color formed was measured using a UV-Vis spectrophotometer (Genesys 10 S, China) at a wavelength of 620 nm. The resulting absorbance was analyzed by plotting on a standard curve, and the amylose content

was calculated based on the relationship between the sample absorbance and the pre-determined standard curve. The amylose content in Papua Sago Starch (PSP) was 27.22%, which is relatively similar to the study by Picauly that recorded 27.18%, but lower compared to the study by Polnaya] at 35.13% and Purwani at 37.24% [24, 25].

These differences might have been due to variations in PSP sources, starch processing methods, or different analytical methods. Amylose content tended to decrease with increasing acid concentration (see Table 2). Research conducted by experts also showed that the amylose content of starch after acid hydrolysis was lower than that of natural starch.

Table 2. Chemical properties of sago starch and acid hydrolysis.

Treatment	Amylose (%)	Resistant Starch Content (%)
Sago Starch	27.22±0.04a	6.54a
HCl 1.1 N	22.97±0.13ab	6.01ab
HCl 2.2 N	20.26±0.38b	5.07ab
HCl 3.3 N	18.29±0.29b	3.90b

There was a slight increase in the degree of starch crystallinity after acid hydrolysis, with the amylose content decreasing from 27.5 to 24.8% using 1.0 N HCl. The researchers concluded that the acid treatment reduced the amylose content in all types of starch tested, with the decrease ranging from 3.1 to 6.4%.. The decrease in amylose content in sago starch can be attributed to the hydrolysis reaction that caused the release of smaller molecules that are water-soluble and too short to form complexes with iodine.

4. Conclusion

Scientific studies on the revitalization of sago forest ecosystems reveal significant regional differences in sago production. The Meranti Islands, for example, have much lower productivity compared to South Sorong and Sarawak, Malaysia. To enhance the productivity and sustainability of sago raw materials, revitalization and intensification of sago forests in eastern Indonesia are essential. This effort aims to increase sago production and contribute to the SDGs, particularly in food security, environmental sustainability, and community welfare. Protein content analysis of sago worms shows variations between thorny and non-thorny stems using the Kjeldahl method. In Halmahera, North Maluku, the total protein content of sago worms is 4.0575%.

Additionally, the study analyzed the amylose content in Papua Sago Starch (PSP) and the effect of acid hydrolysis on its chemical properties. PSP has an amylose content of 27.22%. Acid hydrolysis with HCl can reduce amylose content, potentially increasing the starch's crystallinity and affecting its physical and functional characteristics.

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