UPLIFTING UNDERUTILIZED CROPS FOR ECONOMIC AND INDUSTRIAL IMPORTANCE: SAGO (*Metroxylon sagu* Rottb.)

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Abstract

Global climate change has threatened food security, particularly the production of seasonal food crops. The hope for food in the future will rely on annual plants in the form of trees, which are relatively adaptable to climate change, one of which is sago. Currently, sago's potential has yet to be fully utilized, and it is only used as an alternative commodity to rice and wheat. Sago covers 6.5 million hectares worldwide, with the majority in Indonesia (5.5 million hectares) and an estimated production of 22.3 million tons annually. Sago can be harvested at the age of 10-12 years and can be grown through cultivation. Sago starch is much more productive than other carbohydrate crops like wheat, corn, rice, and cassava. Sago pith can be processed to produce sago starch. Sago starch primarily comprises carbohydrates like wheat flour, tapioca, and rice flour. Sago starch can be a staple food, resulting in biscuits, noodles, and other widely accepted and known food products such as brownies or cakes. The quality of sago starch can be improved by modifying it with Heat Moisture Treatment (HMT). HMT-modified sago starch can be used to replace wheat flour in industrial applications. In addition to starch, other parts of the sago tree can be used to make house roofs, house floors, animal feed, sago worms, and crafts. The findings of this study show that sago is a plant species with the potential to be developed as a strategic economic and industrial commodity.

Keywords: agroindustry, climate change, food security, sago, strategic

Introduction

Global climate change has threatened food security, particularly the production of seasonal food crops. The hope for food in the future will rely on annual plants in the form of trees, which are relatively adaptable to climate change, one of which is sago. Currently, sago's potential has yet to be fully utilized, and it is only used as an alternative commodity to rice and wheat. Sago covers 6.5 million hectares worldwide, with the majority in Indonesia (5.5 million hectares) and an estimated production of 22.3 million tons annually (Al Manar 2023).

Sago can be harvested at the age of 10-12 years and can be grown through cultivation. Sago starch is much more productive than other carbohydrate crops like wheat, corn, rice, and cassava. Among the common starch crops in Southeast Asia and the Pacific, rice, cassava, and sago stand out. However, it is sago that holds the highest promise of providing low-cost raw materials for high-value fermentation products, making it a unique and intriguing contender (Flores, 2008). Sago can generate 10-25 tons of dry starch per hectare per year, whereas corn produces just 5.5 tons, rice produces 6 tons, and cassava and potato produce 10-15 tons (Sumaryono, 2007). One sago tree may yield between 180 and 200 kg of dry sago starch, equivalent to an adult's annual energy-carbohydrate requirement (Yamamoto, 2011).

Sago pith can be processed to produce sago starch. Sago starch primarily comprises carbohydrates like wheat flour, tapioca, and rice flour. Sago contains carbohydrates that can be converted into sugar and bioethanol. Therefore, it has the potential to provide food and energy security for the nation's future (Hayati et al., 2014). This research aims to determine the history of sago utilization, the possibilities for sago utilization in the economy and industry, and the potential for sago development to improve world food security.

History of Sago

The sago palm was significant to the early inhabitants of Southeast Asia, and it was one of the first crops used as part of their sustenance strategy (Avé, 1977; Rhoads, 1982; Flach, 1983). According to geographer Carl O. Sauer, as the native palm became domesticated in Southeast Asia, freshwater cultures could exploit it in various ways, including the manufacturing of flour, medicines, fish poisons, and fishing nets and lines. According to Sarawak Melanau history, the Melanau have always eaten sago, even though they claim rice is their staple meal (Morris, 1974). Sago has also been a staple cuisine for people in other regions of the world. According to Tarver and Austin (2000), during the Chinese Tang Dynasty (618 to 907 CE), sago seeds from palms grown in Southeast China competed with pulverized grains for use in cakes. The sago palm has been essential to the people of the Southwest Pacific from ancient times to the present, with stands of *M. sagu* and *M. rumphii* providing staple meals for millions of people for millennia (McCurrach, 1970).

Indonesia has a tropical climate with plenty of rain and sunlight; thus, trees are the natural vegetation that grows there. According to this, Indonesian forefathers have consumed tree-derived foods from ancient times, including sago (Al Manar, 2023). This is further supported by the discovery of palm of life reliefs, specifically sago, aren, lontar, coconut, and areca nut in various Indonesian temples (Tyassuma & Pasiak, 2019). One of the reliefs of the palm of life is found in Borobudur Temple, built in the 8th century (Figure 1). Sago is the primary dietary component in traditional communities and plays a vital role in myths and rituals symbolic of plant germination and human generation (Ruddle et al., 1978). The sago tree has been recognized as the oldest food crop for humans (Avé, 1977).

Figure 1. The reliefs of the palm of life in Borobudur Temple

According to Marco Polo's travel notes, an area on the island of Sumatra produces a type of camphor of significantly more excellent quality than others. This region has no wheat or corn, yet the locals eat rice, milk, and wine made from sugar palm trees. The Fanfur people also have a tree that they use for food. The trunk is tall and big, allowing two persons to hold it. When the outer bark is removed, a lignified structure is discovered to be about three inches thick, with the middle packed with pith, which yields flour. The pith is placed in a vessel filled with water and agitated with a stick, allowing the fibers and other impurities to rise to the surface while the pure flour settles to the bottom. After this, the water is poured out, and the leftover flour, free of all foreign matter, is used to make cakes and other pastries. Marco Polo frequently ate this, which has the appearance and taste of barley bread, and brought some with him to Venice (Figure 2). According to Wright (2002), the Malays refer to the tree as *rumbiya* or *puhn sagu* (sago palm).

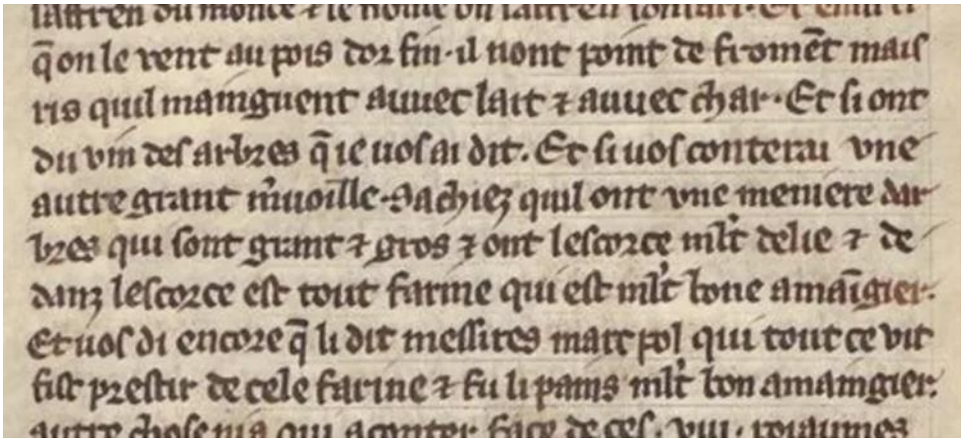
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Figure 2. Food in Barus based on the book Les voyages de Marco Polo de Venise (1350)

In Figure 2 it is written that “*Il nont point de froment mais ris quil mainguent auuec lait et auuec char. Et si ont du vin des arbres que ie uos ai dit. Et si uos conterai une autre grant m’uoille. Sachiez quil ont une meniere darbres qui sont grant et gros et ont lescorce mlt delie et de danz lescorce est tout farine qui est mlt bone a maingier. Et uos di encore que li dit messires Marc Pol qui tout ce vit fut prestir de cele farine et fu li pains mlt bon a maingier*” (They have no wheat, but they eat rice with milk and meat. And they have the wine from the trees that I mentioned earlier. And now I will tell you about another magnificent marvel. You should be aware that they have an enormous and dense tree with loose/thin bark and that the starch contained within it is highly nutritious. And I'll tell you that Mr. Marc Pol, who lived through all of this, tried this starch and created delicious bread). This demonstrates that humans have used sago since antiquity, with sago starch being turned into various food products.

According to Afdeeling Handel (1919), sago was exported to Singapore, Penang Island, Malacca, and Labuan during the Dutch East Indies. From 1913 to 1917, Riau sago from Lingga Island and Selat Panjang had the highest export value in the archipelago, surpassing Ambon, Borneo (Kalimantan), Aceh, Tapanuli, Celebes (Sulawesi), Bali, Lombok, Jambi, Bengkulu, and Belitung. During that time, Lingga sago production competed solely with Indragiri, also from the Riau Residency. In 1913, processed sago exports were 4,752 tons, followed by 4,805 tons in 1914, 4,496 tons in 1915, 4,467 tons in 1916, and 3,797 tons in 1917.

Characteristics of Sago

Sago is a palm species that produces scale-covered fruit. Sago fruits have 18 rows of scales distributed lengthwise (Rauwerdink, 1986). Sago has been recognized as several species, including *M. sago, M. amicarum, M. vitiense, M. salomonense, M. warburgii*, and *M. paulcoxii*. Several species of sago in the genus *Metroxylon* exhibit distinct physical traits. Based on inflorescence characteristics, only *M. amicarum* produces lateral inflorescences from the leaf axils, whereas the other five species produce terminal, racemose inflorescences. *M. amicarum*'s lateral inflorescences are polycarpic, but other species' terminal inflorescences are hepaxanthic (monocarpic) (Ehara, 2018).

People in several nations refer to sago by different names. Sago is known as "*rumbia*" in Malaysia and Indonesia. Sago is known as balau in the Melanau population of Sarawak, and several ethnic groups in Sarawak have alternative names for it, including *rumbia* (Malay), *umbizo* (Kadazan), *tumba* (Gorontalo), and *humbia* (Sangir) (Shin, 2015). Sago is known in the Philippines as *lumbia* (Bisiya), *lumbiag* (Sulu), and *lumbiya* (Cebuano) (Dutton, 1994). In Papua New Guinea, sago is commonly referred to as *saksak* in Tok Pisin and *lohu* in everyday language. Several nations have similar names for sago, including Myanmar (*thagu-bin*), Cambodia (*sa kuu*), and Thailand (*sa khu*) (Flach, 1997).

Local communities in Indonesia refer to the sago plant by a variety of names, including *kirai* (Sunda), *ambulung*, *kesulu*, *tembulu* (Java), *lapia* (Ambon and Seram), *bulung* (Madura), *rambia, hampia, rumpia, ripia, lepia, hula*, or *huda* (Maluku) (Flach 1997). Sago is known by different names in Kalimantan's Dayak community, including *hambie*

(Bakumpai) and *lumbioh* (Tidung). In Sulawesi, sago is also known as *rumbia* and *humbia* (Sangir) (Dutton, 1994).

People commonly distinguish between thorny and thornless sago (Figure 3). People group sago accessions based on the presence of thorns (Masluki, 2022). This is consistent with Pratama et al. (2018)'s conclusion that people use morphological traits to distinguish various sago accessions, including the presence of thorns, thorn patterns, stem shape, and stem height. This differs from Novero et al. (2012), who stated that the existence of thorns does not guarantee that a sago species is different or the same. The presence or lack of thorns in the vegetative phase does not correlate with genetic variation in sago (Kjaer et al., 2004). According to Novero et al. (2012), the occurrence of thorns on sago plants is an epigenetic event affected by the environment. This is also consistent with the remark made by Ehara et al. (2003), who stated that the presence of thorns on the petiole and rachis did not affect sago's genetic distance response. In addition, thorny sago seeds can be formed from thornless sago seeds (Ehara et al., 1998).

(a) (b)

Figure 3. (a) thorny sago; (b) thornless sago (Al Manar et al., 2023)

Sago Production Potential

Rice, cassava, and sago are the primary starch sources in Southeast Asia and the Pacific. Among the three species, sago has the highest promise for delivering low-cost raw materials for high-value fermented products (Flores, 2008). Sago contains carbohydrates that can be converted into sugar and bioethanol, indicating that it has the potential to provide food and energy security for the nation's future (Hayati et al., 2014). Sago has the potential for a vast and inexpensive starch source (Karim et al., 2008; Singhal et al., 2008). Sago can yield up to 25 tons of starch per hectare at the end of an 8-year growth cycle (Zhu, 2019). Sago starch productivity is significantly higher than other major crops like corn, rice, and cassava. Sago can generate 10-25 tons of dry starch per hectare per year, whereas corn produces just 5.5 tons, rice produces 6 tons, and cassava and potato produce 10-15 tons (Sumaryono, 2007). Climate change has also resulted in inadequate growth for most seasonal agricultural commodities. Furthermore, the widespread use of chemical fertilizers in agricultural lands has altered the physical and chemical qualities of the soil (Savci, 2012). The hope for future food supply will be based on tree stands generally resilient to climate change, one of which is sago (Al Manar, 2023).

The sago palm generates much starch, around 150-300 kg of dry starch per plant (Konuma, 2018). Several studies have shown that the average starch production varies significantly at each location, including Aimas District (Sorong) of 183.40 kg tree-1 (Ahmad et al., 2016), Mioko (Mimika) of 143.87-402.09 kg tree-1 (Pratama et al., 2018), and Haripau (Mimika) of 104.38-275.04 kg tree-1 (Nurulhaq et al., 2022). Height, diameter, moisture content, and sago stem yield all impact starch output (Al Manar et al., 2023).

Sago offers various advantages over rice, including increased productivity and lower development and manufacturing costs (Bantacut, 2011). According to Bantacut's (2011) research, one kilogram of rice equals 1.04 kilograms of sago starch. The consumption needs for sago flour per capita, 135.2 kg/capita/year, is calculated using the calorie content equivalent to 130 kg of rice/capita/year. Based on calorie content and production, a comparison of harvest areas necessary for each person to meet calorie needs is made. If rice is the sole staple food source, the land required is enormous; one hectare of rice crop can only feed 25 people. With this equivalent value, a population of 270 million requires six million hectares of rice fields or a harvest area of approximately 12 million hectares. On the other hand, sago only needs about 2.2 million hectares, so the total area required is two million hectares. Based on this notion, sago outperforms rice.

Table 1 Comparison of sago and rice production efficiency

Parameters	Rice	Sago
Consumption (kg/capita/year)	130	135
Productivity (ton/ha)[a]	3	25
Required harvest area (m2/people/year)	430	54
Indonesian population in 2010 (million people)	230	230
Indonesia’s consumption needs (tons)	29.900.000	33.750.000

Indonesia's harvest area requirements (ha)	9.890.000	1.350.000
Area requirements (ha/year)[b]	4.945.000	1.350.000
Assumed population in 2030 (million people)	270	270
Land area requirements 2030 (ha)	5.805.000	1.584.000

[a]With intensive cultivation
[b]The assumption is that rice is harvested twice/year and sago is 40 trees/ha/year.
Source: Bantacut (2011)

According to Djoefrie et al. (2014), the area of sago in Indonesia is 5,579,637 ha, with an estimated production of 22.3 million tons annually. The majority of this area is in forests (Table 2). Sago can grow naturally or be planted in neglected wetlands and peat swamps (Ruddle, 1977; Syauki et al., 2022). Sago trees have erect trunks that can reach 7-15 meters in height with an average diameter of 120 cm at the base (Flach & Schuiling, 1989).

Table 2 Area and estimated production of sago in Indonesia

No	**Location**	**Area (ha)**	**Persentage (%)**	**Estimated production (ton year^{-1})**
1	Papua	4,749,424	85.12	18,997,696
2	West Papua	510,213	9.14	2,040,852
3	Maluku & North Maluku	60,000	1.08	240,000
4	Sumatra	60,000	1.08	240,000
5	Sulawesi	30,000	0.54	120,000
6	Kalimantan	20,000	0.36	80,000
7	Others	150,000	2.68	600,000
	Total	**5,579,637**	**100.00**	**22,318,548**

Source: Al Manar (2023)

Utilization of Sago

The community has used sago for a variety of purposes. The sago tree's primary use is for its pith, which is harvested and converted into sago starch. The community uses sago starch to manufacture a variety of processed meals. The South Sulawesi community uses sago as a raw source to make dry sago starch and kapurung. The Bangka population uses sago starch to make pempek, otak-otak, and other crackers (Levyda et al., 2021). Meanwhile, coastal groups in Papua employ sago starch for papeda and sagu lempeng (Syauki et al., 2022). It's fascinating to see the diverse ways in which Indonesian communities utilize sago trees. Beyond the use of pith as starch, they also make use of other parts such as roots and leaves, as well as sago processing waste like bark, sago pulp, and sago waste. Table 3, a comprehensive overview, provides a detailed account of these various uses.

Table 3. Utilization of sago trees by people in Indonesia

No	Utilized parts	Utilization
1	Sago roots	Medicine
2	Sago pith	Extracted starch will be processed into different food items
3	Bark	Roads (planks), firewood, home and garden fences
4	Leaves	Roofs
5	Sago fronds	House walls, roof ropes, craft supplies, traditional wedding traditions
6	Sago pulp	Animal feed and fertilizer
7	Sago waste	Animal feed
8	Sago pulp	Vegetables
9	Sago worms	Source of protein and fishing bait

Source: Haruna et al., (2022); Al Manar et al., (2024)

The community uses sago leaves to make roofs (Figure 4). Sago leaves are used to make roofs and walls of kelongs, which are sites for sea fishing, in the Lingga Malay community of the Riau Islands (Al Manar et al., 2024). People in Luwu, South Sulawesi, as well as the Banjar ethnic community in South Kalimantan, utilize sago leaves to make roofs (Syahdima et al., 2013).

Figure 4. Utilization of sago leaves as a roofs (Al Manar et al., 2024)

The Lingga Malay community uses sago fronds to make house walls and roof ropes (Al Manar et al., 2024). Meanwhile, in Luwu, South Sulawesi, sago fronds are utilized in crafts and traditional wedding ceremonies (Haruna et al., 2022). The community uses sago tree components and wastes from sago starch manufacturing. The community uses sago pulp as animal feed, particularly for chickens and ducks. Sago pulp still contains significant carbohydrates and fibre (Awg-Adeni et al., 2013). Additionally, dry sago pulp includes 58.0% starch, 23.0% cellulose, 9.2% hemicellulose, and 4.0% lignin (Linggang et al., 2012).

Bioprospecting of Sago

Sago is used as both food and medication. Several traditional tribes have employed sago roots for medicinal purposes. Thais have utilized sago roots as an antidiabetic (Andrade et al., 2020). This is due to antioxidant activity in sago roots. People in Radda Village, North Luwu, utilize sago roots to treat fever, back pain, gout, and impotence by boiling and drinking them (Syahdima et al., 2013). Papuans use sago roots as an antimalarial medication, and cooked sago roots treat digestive problems and prevent colon cancer (Budiarti et al., 2020; Kadir et al., 2022). The Anak Rawa Tribe in Siak, Riau, uses sago roots to stimulate breast milk by crushing and consuming them. Sago roots used are those that hang down and do not touch the ground (Sariasih, 2019). The natives of South Kalimantan have also used sago roots to treat diarrhoea (Bakhriansyah et al., 2011). Bakhriansyah et al. (2011) found that sago roots contain alkaloid, tannin, and saponin components (Table 4).

Table 4. Chemical composition of sago roots

Chemical compounds	Result
Alkaloids	+
Tannin	+
Saponin	+

Source: Bakhriansyah et al. (2011)

Some people have used sago leaves as medication to cover fresh wounds or infected body parts while they recover (Latayada & Uly, 2016). Sago leaves, combined with other herbal plants in a polyherbal mixture, treat amenorrhea and polymenorrhea (Flach, 1997). People in Radda Village, North Luwu, use young sago leaves to relieve menstrual pain by boiling them and drinking the water (Syahdima et al., 2013). People in the Tamansari District of Bogor have also utilized sago leaves as medicine to treat digestive tract ailments (Roosita et al., 2008). Nurlila et al. (2021) successfully identified the chemical componens found in sago leaves. Sago leaves contain various chemical substances, including alkaloids, phenols, flavonoids, saponins, tannins, and steroids (Table 5).

Table 5. Results of identification of chemical compound content of sago leaf extract

Compound class	Reagent name	Result	Information
Alkaloids	Mayer	-	No yellowish precipitate was formed
	Dragendorff	+	An orange precipitate is formed
Phenol	$FeCl_3$	+	A bluish-green or dark blue colour is formed
Flavonoids	HCl	+	Yellow colour is formed
Saponin	HCl	+	Foam is formed
Tannin	$FeCl_3$	+	A blackish-blue or blackish-green color is formed
Triterpenoids	H_2SO_4	-	No brownish or violet rings are formed
Steroids	H_2SO_4	+	A bluish-green ring colour is formed

(+) indicates the presence of secondary metabolite chemicals, whereas (-) indicates the absence of secondary metabolites.
Source: Nurlila et al. (2021)

Sago for Global Food Security

The conflict between Russia and Ukraine has impeded the distribution of wheat produced by the two countries. This has also impacted numerous countries that rely on wheat products from both countries. According to the FAO (2022), up to 50 nations in Asia and Africa depend on Russia and Ukraine to supply 30% of their wheat food demand, with 26 countries meeting 50% of their wheat requirement through imports from Russia and Ukraine. Russia and Ukraine are the world's top wheat producers, accounting for over a quarter of worldwide wheat commerce (Mottaleb et al., 2022). The ongoing conflict between Russia and Ukraine has the potential to undermine food security in developing countries (Bentley et al., 2022; Chikava, 2022; Douglas, 2022). According to data from the Food Security Information Network and the Global Network Against Food Crises (2023), up to 218.6 million people face severe food insecurity, and at least 59 countries and territories require immediate food aid. The conflict between Russia and Ukraine has also had an indirect favourable impact on the growth of local food commodities in both countries, especially Indonesia. The restriction on the distribution of wheat products from the two nations provides a chance to harness the potential of Indonesia's native food resources, one of which is sago.

In 2006, imaging data analysis revealed 23.6 million hectare of potential sago habitat across Indonesia. Potential sago habitats include swamp thickets, swamps, secondary mangrove forests, primary swamp forests, and secondary swamp forests. If the prospective sago production is estimated to be 10 tons per hectare, Indonesia's production potential is 94.5 million tons annually (Table 6).

Table 6. Sago production potential is based on potential habitat

No	Location	Area (ha)	Estimated production (ton year^{-1})
1	Kalimantan	9,207,172	92,071,720
2	Papua	7,722,286	77.222.860
3	Sumatra	6,166,400	61.664.000
4	Java & Bali	191,645	1.916.450
5	Sulawesi	173,198	1.731.980
6	Maluku	166,815	1.668.150
	Total	**23,627,516**	**236.275.160**

According to Table 6, Indonesia's sago production potential can be leveraged for global food security. This is because sago plants are more resilient to climate change than seasonal crops like rice and wheat. Wheat is the world's most widely produced food commodity, and output has expanded year after year. Wheat is a versatile food ingredient that can be employed as a texturizer, binder, emulsion stabilizer, moisture retainer, or coating agent, and it is reasonably priced (Vanier et al., 2020). Wheat flour is ordinary in bread (with or without yeast) and sweet and savoury cakes (Samancı, 2020).

Conclusion

Sago has been the staple food of the Indonesian people since ancient times, as evidenced by the relief of the palm of life since the 8th century. Sago is a plant species that is adaptive to global climate change, so it has the potential to be developed as a staple food during the global climate crisis. In addition, sago has high production and economic potential if developed as a sustainable food industry commodity. Based on the existing potential, Indonesia can be a carbohydrate food supplier for the world's population by developing potential habitats for sago.

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