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Production potential of sago forests in different habitat types in Sentani watershed, Papua, Indonesia

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Abstract. *Dimara PA, Purwanto RH, Auri A, Angrianto R, Mofu WY. 2023. Production potential of sago forests in different habitat types in Sentani watershed, Papua, Indonesia. Biodiversitas 24: 3924-3931.* Sago possesses a substantial carbohydrate content, rendering it a promising alternative for ensuring food security. This study aimed to assess the potential for sago production in Sentani watershed, Papua Province, Indonesia across diverse growing environments, namely dryland, temporarily flooded, and prolonged flooded habitats. This research combined spatial analysis and field-based study. Spatial analysis utilized Landsat 8 satellite imagery from the year of 2021 analyzed using supervised classification and overlay methods to differentiate sago habitat types. Field study used the combination of line transect and systematic circular plot methods to assess the structure and composition of sago vegetation. Field study also determined starch yield of sago plant by felling the plant and extracting the starch. The results showed that there are 13 local sago varieties according to the Sentani language, namely *ebhesum, folo, hobholo, manno, phane, phara, rondo, ruruna, osukhulu, wani, yakhalobe, yakhe,* and *yebha*. Sago plants growing on dryland, temporarily flooded, and prolonged flooded habitats covered an area of 1,246.35 ha (15.89%), 4,820.49 ha (61.46%), and 1,775.92 ha (22.64%), respectively. The plant grew in clumps with 10, 13, and 8 varieties in the dryland, temporarily flooded, and prolonged flooded habitats, respectively. The total starch production reached 13,999.57 tons.year^{-1} with production in dryland, temporarily, and prolonged flooded habitats amounting to 2,132.88 tons.year^{-1}, 1,031.39 tons.year^{-1}, and 1,335.31 tons.year^{-1}, respectively. Meanwhile, the areas with the highest starch production were West Sentani, Sentani, and Waibu Sub-districts for the dry, temporary, and flooded habitats. Our findings suggest that two sago varieties, namely *phara* and *yebha,* are recommended for cultivation because they are more adaptive and have high starch yield compared to other sago varieties.

Keywords: Habitat types, *Metroxylon sagu*, sago production, Sentani watershed, starch

INTRODUCTION

Sago (*Metroxylon sagu* Rottb.) is one of the main food sources for some communities in several countries around the world. In Indonesia, the plant generally grows in swamp and tidal peatland areas and takes 8-12 years to reach mature phase (Ehara et al. 2018). The dry starch, which is extracted from the pith of the plant stems, can yield 150-1500 kg per plant (Konuma 2018; Yamamoto et al. 2020a). The sago starch contains a high level of carbohydrate which has a great potential to be utilized as an alternative food staple to solve food security issues (Bujang et al. 2018; Lim et al. 2019). Over the past decade, there is significant increase in the processing technology, modification and application of sago starch for various food and non-food products. However, the increasing utilization of sago starch might lead to overexploitation of sago plants in the wild which might threaten their existence in the future. Therefore, the exploitation of sago plants needs to consider technical, environmental, and economic aspects for their sustainability.

Sago plant is a type of palm that can be found in wet tropical regions in various habitats, such as freshwater swamps, peat swamps, along riverbanks, around water sources, dryland, temporarily flooded land, or prolonged flooded land (Hussain et al. 2019). Differences in habitat and environmental factors affect the growth and yield of sago, but in general, it needs a poor drainage system to grow. Generally, this species grows in area with elevation of 0-400 m asl, while sago that grows in area with altitude above 400 m asl might result in slower growth and lower starch content (Yamamoto et al. 2020a). In the temporarily flooded habitat, the plant can grow taller, while in the prolonged flooded habitat, the growth is outcompeted by grasses and herbs, resulting in limited space. Under prolonged waterlogging conditions, the photosynthetic capacity tends to be suboptimal (Azhar et al. 2020a). In the dryland habitat, the growth is outcompeted by other forest plants, leading to competition for sunlight and soil nutrients. Sago plant in the dryland habitat has very few clumps per hectare and limited offspring but produces relatively high starch per plant. Although sago plants are very adaptive and can grow in wide range of habitats, environmental pressures (soil, climate and hydrology) might result in non-optimal growth which also affects sago production (Husain et al. 2019; Lim and Chung 2020). The plant can also grow on marginal lands such as peatlands, which are considered less fertile for cultivating food and plantation crops (Lim and Chung 2020). However, sago plants on peatlands exhibit stunted growth, reduced leaves number, and a longer time to reach the mature phase.

A significant potential for sago forest exists in the Jayapura District on Papua Island. The natural sago forests in this area have long been utilized by the local communities. Sago forests in the Sentani watershed, Jayapura District grow on flat to hilly land at elevations ranging from 0 to 450 m asl (Dimara et al. 2021). In Papua there are 21 local sago varieties differentiated based on morphological characteristics including the presence of thorns, stem height and diameter, the color of leaf sheaths, and the color of shoots and starch (Matanubun 2015; Riyanto et al. 2018; Abbas et al. 2020). Such high diversity of sago varieties provides opportunities for the development of sago for its sustainable utilization as food and energy source. Nonetheless, this requires baseline information regarding the suitable lands potential for sago production based on habitat types. Therefore, this study aimed to estimate the potential sago production in different types of habitats (i.e., dryland, temporary flooded and prolonged flooded area) in Sentani watershed, Jayapura District. The integration of the diversity of sago varieties and habitat types is expected to provide valuable information on production potential of sago starch in the region.

MATERIALS AND METHODS

Study area and period

This study was conducted in sago habitats located in the Sentani watershed from March to October 2022. Administratively, the habitats were spread across six Sub-districts, namely East Sentani, Sentani, West Sentani, Ebungfau, Kemtuk, and Waibu in Jayapura District, Papua Province, Indonesia. Geographically, the Sentani watershed is located between 2°27'46.88"-2°44'7.95"S and 140°16'44.76"-140°38'25.37"E. The research was conducted in three different habitat types: dryland (1246.35 ha), temporary flooded (4820.49 ha) and flooded (1775.29 ha). The research location is shown in Figure 1.

Research procedures

This research combined spatial analysis and field-based study as explained below.

Spatial analysis

We used spatial data generated from Landsat 8 imagery of the year 2021, downloaded from the USGS website (https://glovis.usgs.gov). Other spatial data included thematic maps of elements such as elevation, slope, soil type, rainfall, river, and groundwater distribution obtained from the National Geospatial Information Agency (BIG) with a scale of 1:250,000. The satellite image was radiometrically and geometrically corrected (USGS 2017). Furthermore, the supervised classification method was utilized for the satellite images and the combination of bands 7 (Shortwave Infrared 2) - 5 (Near Infrared) - 3 (Green) proved to be the most effective in identifying sago habitats.

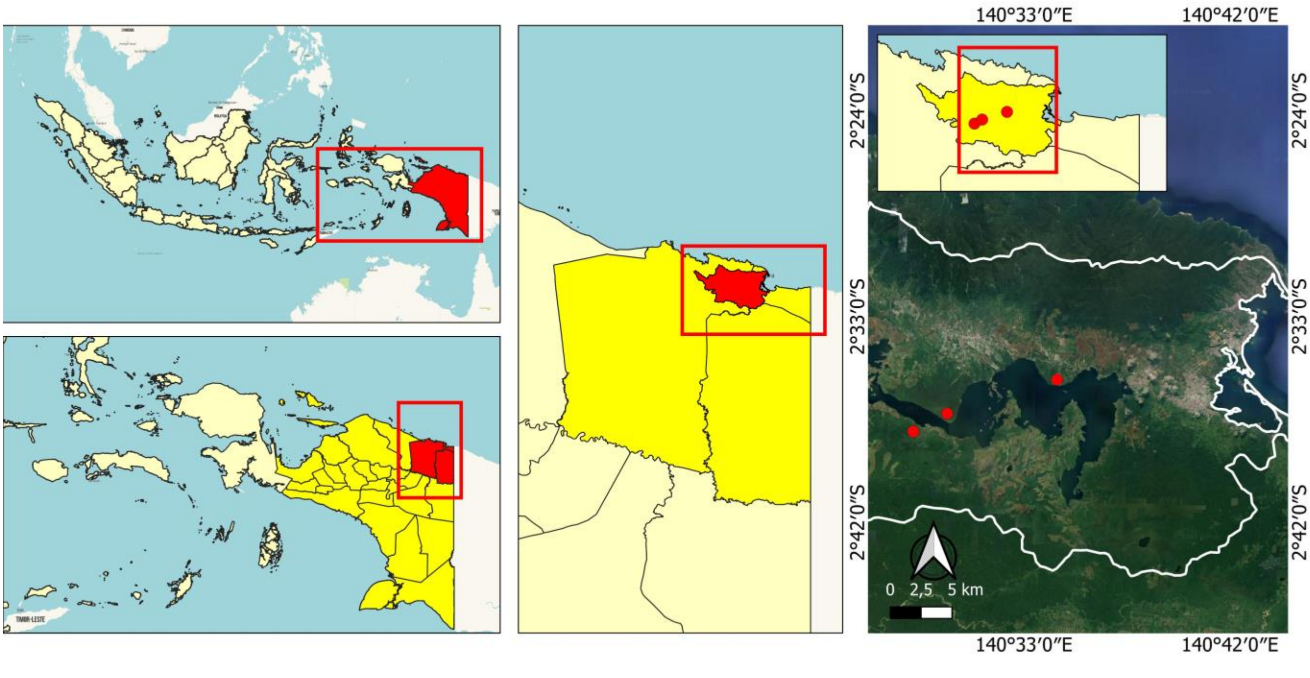

Figure 1. Map of studied area in Sentani watershed, Jayapura District, Papua, Indonesia

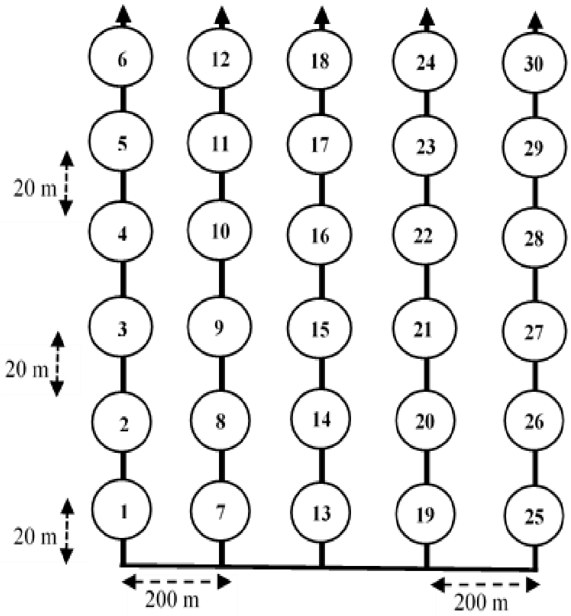

Figure 2. Diagram of sampling methods using the combination of line transect and systematic circular plots

The creation of the habitat type map involved the process of classification analysis, Euclidean distance calculation, buffering, interpolation, and overlaying the sago forest map with 5 environmental parameters, such as elevation, slope, soil type, rainfall, optimal river distance, and groundwater depth, to obtain the distribution of the sago habitats. The resulting map was then divided into 3 categories of sago habitat, namely dryland, temporarily flooded, and prolonged flooded habitats. In this study, dryland habitat referred to area not being flooded at all time, temporarily flooded habitat referred to areas with intermittent events of water inundation and dry condition and is influenced by the water tides of the lake, while prolonged flooded habitat referred to areas experienced prolonged inundation, typically lasting for more than 1 month (Louhenapessy et al. 2010).

Field-based study

The observations of sago plant structure and composition were conducted using the combination of transect lines method and circular plots established around the clumps of sago (Lilleleht et al. 2014; Arland et al. 2018) in the prolonged flooded, temporarily flooded, and dryland habitats (Figure 2). At each habitat type, five transects at a distance of 200 m between transects were established, resulting in 1 km baseline. Along each transect, 6 circular plots were systematically placed at a distance of 20 m from the plot's central point, resulting in a total of 30 plots per habitat type and 90 plots for the whole study. This number of plots was determined considering the requirement for normally distributed data.

Observations and measurements were carried out at each plot, including (i) measuring the clump area, (ii) observing the varieties and number of mature sago plant, (iii) measuring the total height, sheath-free height, and diameter of the mature plant, and (d) measuring stem volume. Furthermore, environmental factors such as air temperature, light intensity, air humidity, and soil pH were also measured. The measuring instruments used in this study were Haga meter, compass meter, GPS, diameter tape, Lux meter, Thermohygrometer, Scales, pH meter. Stem volume was calculated using the formula $Vt = ¼ \pi D^2 x H x f$, where D represented diameter at breast height, H was height, π was equal to 3.14, and f was the form factor (0.90) (Dewi et al. 2016).

Field observations showed that: (i) temporary flooded habitat experiences water immersion when it rains, and is inundated for one to two weeks or a maximum of one month. If there is no rain for some time, the habitat conditions will dry up. Temporary flooded habitat has water inundation with height of 10-15 cm above ground level, where it takes between 1-3 months for the habitat to become dry. (ii) Prolonged flooded habitat experiences water inundation for more than one month. Logged water can come from rainwater or river water. In the prolonged flooded habitats, the height of the inundation reaches 20-30 cm above ground level in the dry season and 50-70 cm in the rainy season. (iii) Dryland habitat has never experienced water inundation, either from rainwater or river water.

Data analysis

Sago production was determined by felling mature plants that met the harvesting criteria and measuring the resulting starch production. The processing of sago to obtain starch involved several stages, including felling, cutting, stem splitting, pith crushing, starch extraction, sedimentation, and packaging. The starch obtained was the final result used to determine the sago production per plant (kg). In assessing the production, the habitat area and the average production per hectare were denoted as A_{pi} and P_{pi} , respectively. Therefore, the formula used to calculate the total sago production in the Sentani watershed T_{ps} was expressed as: $T_{ps} = \sum_{i=1}^{n} A_{pi}\, x\, P_{pi}$ (Dewi et al. 2016).

RESULTS AND DISCUSSION

Extent and spatial distribution of sago habitat types

The sago habitats in the Sentani watershed cover an area of 7,842.76 ha, distributed across Ebungfau, Kemtuk, Sentani, West Sentani, East Sentani, and Waibu Sub-districts (Table 1). Sago vegetation around Lake Sentani plays a crucial role that connects the terrestrial and lake ecosystems. Sago plants are distributed at elevations ranging from 0 to 450 m asl, with the largest extent of habitat found at 0 to 100 m asl covering an area of 4,385.63 ha (55.92%). The field observation indicates that sago plants have adapted, grown, developed, and produced well at 0 to 100 m asl. Meanwhile, a lower extent of habitat is found at elevations of 401 to 450 m asl, covering an area of 11.39 ha (0.15%). Sago plant in the Sentani Watershed can grow well at elevations up to 0-300 m asl, but the slower growth of sago is found in habitat with elevation above 300 m asl (Dimara et al. 2021).

The characteristics of the habitats in this region consist of dryland, temporarily flooded, and prolonged flooded habitats. The dryland habitat with the presence of sago plants covers an area of 1,246.35 ha (15.89%). The largest and smallest area of sago on dryland habitat are located in West Sentani and Sentani Sub-districts covering an area of 435.75 ha (34.96%) and 13.33 ha (1.07%), respectively. The distribution includes areas along river streams and lake shores. Suitable land for sago growth includes soils rich in minerals and organic matter, freshwater areas where roots are not submerged in water, and areas not frequently affected by tidal waters (Ehara et al. 2018).

The temporarily flooded habitat covers an area of 4,820.49 ha (61.46%). The largest and smallest area of temporarily flooded habitats are located in Sentani and West Sentani Sub-districts covering an area of 1,728.76 ha (35.86%) and 260.26 ha (5.40%), respectively. Soil hydrology largely determines the conditions for sago growth and production (Louhenapessy et al 2010).

Sago plant in the prolonged flooded habitat covers an area of 1,775.92 ha (22.64%). The largest and smallest area of the prolonged flooded habitats are located in the East Sentani and Ebungfau Sub-districts covering areas of 576.38 ha (32.46%) and 226.57 ha (12.76%). Continuous water inundation covering the roots can affect the oxygen supply for their growth. Oxygen deficiency also leads to damage in the root tissues, thereby hindering sago growth (Azhar et al. 2020b).

The species *Metroxylon sagu* Rottb in this region is divided into 13 local varieties according to the Sentani language, namely *ebhesum, folo, hobholo, manno, phane, phara, rondo, ruruna, osukhulu, wani, yakhalobe, yakhe,* and *yebha*. Thorny varieties include *ebhesum, manno, phara, rondo, ruruna,* and *yakhalobe*, while non-thorny varieties are *folo, hobholo, phane, osukhulu, wani, yakhe,* and *yebha* (Matanubun et al. 2015). The results show that *Metroxylon sagu* Rottb of the *phara* variety can adapt and reproduce well in dry and temporary habitats. *Phara* in the sago population has a larger number of plant than the other varieties in the dryland and temporary flooded habitats. *Phara* and *yebha* have shown excellent adaptation abilities and high production. The physiological, anatomical, and phenological characteristics are affected by the biophysical variables and influence their interactions and associations with other species (Crausbay and Martin 2016). The observations show that Metroxylon sagu Rottb of the *yebha* variety can adapt and reproduce well in the prolonged flooded habitat. Increased inundation also results in vegetation community shifts (Normand et al. 2017).

Population of mature sago plants in the Sentani watershed

Sago plant grows in both large and small clumps. The findings show that the density of sago clumps ranges from 63 to 77 clumps ha^{-1}. The distribution pattern tends to be clumped with the distance of 2.57-5.81 m, 4.29-12.94 m, and 6.55-14.82 m on dryland, temporarily flooded, and prolonged flooded habitats, respectively. The suitable area for the habitat of sago plant is likely related to the reachability of sago roots in the soil. The roots of sago plant grow horizontally before the stem formation stage, and subsequently increase on the vertical axis as the plant grows taller and wider in diameter (Miyazaki et al. 2016). On each habitat type, almost impossible to find every clump that has all growth phases such as seedlings, saplings, poles, and plant. Similarly, mature sago plant is not always found at every clump (Louhenapessy et al. 2010). Mature sago plants in the dryland habitat are found at a density of 12 individuals ha^{-1} (Table 4). Sago varieties found growing in the dryland habitats are *phara, folo, rondo, yebha, habholo, manno, osukhulu* and *raruna*. Each clump has 1-2 mature plants with a total height of 11.60 m-15.30 m, a sheath-free height of 5.02 m-10.32 m, and a stem diameter of 44.12 cm-55.70 cm. Plant height and stem diameter are significant factors influencing starch production (Dewi et al. 2016; Yater et al. 2019). The dryland habitat is located at higher elevations compared to the temporarily flooded and prolonged flooded habitats. Elevation factor is closely related to temperature where higher elevation corresponds to lower temperature, affecting plant physiological processes such as stomatal opening, transpiration rate, photosynthesis rate, and plant respiration (Azhar et al. 2018). The low temperature in highland areas prolongs vegetative growth and inhibits flowering in sago plant (Muhidin et al. 2016). The sago plants growing in the habitats at a higher elevation (>100 m asl) are grouped in small clumps, specifically along riverbanks, springs, and valleys with water body during rainfall. These sago clumps are located near dryland and coexist with other woody vegetation. The condition is not optimal due to competition for absorption of nutrients, water, and sunlight. The structure of plant growth phases significantly affects sago regeneration and starch production. The spatial distribution of sago habitat is presented in Figure 3.

Table 1. The extent of sago habitat types in Sentani watershed, Jayapura District, Papua, Indonesia

Sub-district	Sago habitat type						Area (ha)	Percent (%)
	Dryland (ha)	%	Temporarily flooded (ha)	%	Prolonged flooded (ha)	%		
Ebungfau	150.72	12.09	522.24	10.83	226.57	12.76	899.53	11.47
Kemtuk	221.20	17.75	372.10	7.72	-	-	593.30	7.56
Sentani	13.33	1.07	1,728.76	35.86	422.52	23.79	2,164.61	27.60
West Sentani	435.75	34.96	260.26	5.40	-	-	696.01	8.87
East Sentani	44.27	3.55	901.20	18.70	576.38	32.46	1,521.85	19.40
Waibu	381.08	30.58	1,035.93	21.49	550.45	31.00	1,967.46	25.09
Total	1,246.35	100	4,820.49	100	1,775.92	100	7,842.76	100.00
Percent (%)	15.89	-	61.46	-	22.64	-	100.00	-

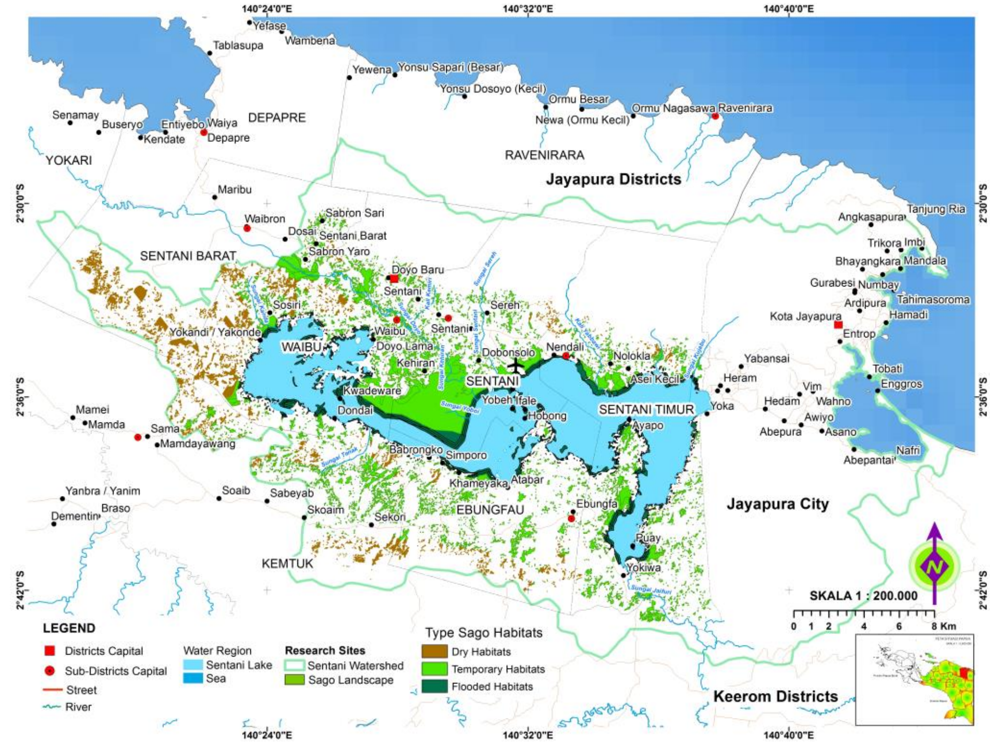

Figure 3. Spatial distribution of sago habitat types in Sentani watershed, Jayapura District, Papua, Indonesia

On the temporarily flooded habitat, there are 16 individuals ha^{-1} of mature sago plants from 11 different varieties. Sago varieties found growing in temporarily flooded habitats are *phara, rondo, osukhulu, manno, yebha, wani, yakhalobe, yakhe, ebhesum, folo* and *phane*. Each clump has 1-2 mature plants with a total height ranging from 8.79-17.42 m, a sheath-free height of 6.85-11.88 m, and a stem diameter of 48.27-55.32 cm. The morphological characteristics in term of stem height, diameter, and bark thickness significantly influence the production potential because starch is stored in the pith (Fathnoer et al. 2020). Furthermore, this habitat has good soil fertility and receives sufficient sunlight. The duration of sunlight exposure in sago habitats ranges from 3 to 6 hours with an average of 4.58 hours. The average measured intensity of sunlight near and between clumps is around 192.31 lux and 457.16 lux, respectively. In contrast, the average measured intensity of sunlight in open spaces reaches 918.14 lux. This means that less than 50% of sunlight intensity enters sago habitats and the air temperature is greatly influenced by sunlight intensity. The optimal temperature for sago growth ranges from 24.5 to 29°C with a minimum of 15°C and relative humidity of 70-90% (Morrison et al. 2012; Okazaki and Kimura 2015; Dimara and Auri 2023). Air temperature affects two plant metabolic processes, namely photosynthesis and respiration. The photosynthetic activity of sago plant is more sensitive to the minimum ambient air temperature than the maximum (Azhar et al. 2018).

On the prolonged flooded habitat, there are 4 individuals per ha of mature sago plants from 4 different varieties, namely *phara, ruruna, folo* and *yakhe*. Each clump has a 0-1 mature plant with a total height of 10.86-17.34 m, a sheath-free height of 8.12-10.47 m, and a stem diameter of 43.12-51.44 cm. Sago plant can grow well in alluvial deposit formations. However, some plants in the prolonged flooded habitat grow slower than those in the dryland habitat. Physical and chemical barriers experienced in waterlogged areas include low bulk density, poor drainage, high water-holding capacity, high acidity, and low availability of macro-nutrients (Anugoolprasert et al. 2012). The water absorbed by the plant roots is used for transpiration and respiration processes, while some are stored in the stem due to the flexibility of the xylem cells. The tension in the xylem relaxes but water continues to be absorbed by the roots when transpiration decreases at night or during rainfall. Sago plant contains more water, resulting in reduced starch production in the stem when the growing area is constantly waterlogged (Miyazaki et al. 2011).

Sago production

Observations indicate that *yebha, phara, yakhalobe, osukhulu,* and *manno* produce red-colored starch, while *ebhesum, folo, hobholo, phane, rondo, ruruna, wani,* and *yakhe* have white-colored starch. The highest wet starch production is obtained from the *yebha* variety with 313.20 kg per plant. This is attributed to the large size of the plant in terms of height and stem diameter, as well as the good land capability. Meanwhile, the lowest wet starch production is observed in the *manno* variety at 54.39 kg per plant. The dimension of stem significantly influence starch production because the longer stem of sago plant will increase the weight and affect the starch content. This variety also has a large canopy size and a high number of leaf sheaths, which impact sago production. Leaves are an important component in starch formation within the plant stem. This is because starch production is highly influenced by the photosynthesis process occurring in the leaves (Yamamoto et al. 2020c). The production is determined by the yield or starch content in the pith of the stem, as well as the height and diameter.

Sago varieties have different morphological characteristics, as well as varying yield potentials. Individually, several varieties are capable of high production even without any maintenance. Starch production is greatly influenced by genetics and the environment. The *yebha, phara,* and *folo* varieties can produce relatively high starch yields. Furthermore, the production is also influenced by the height and diameter of the plant. It also correlates positively with stem weight and starch content in the stem (Ehara et al. 2018). *Manno* has the lowest yield, possibly due to its higher water content in the pith compared to starch, resulting in low content. The measurement results of sago production are shown in Table 5.

The production of two sago varieties with the largest yield (*yebha* and *phara*) is almost the same in all habitat types because they have a wide adaptability to environmental factors. *Phara, yebha, osukhulu,* and *folo* have high starch content (Yamamoto et al. 2020b). The production of sago per plant in the Sentani watershed ranges from 54 kg to 313 kg with an average wet starch weight of 194.9 kg and yield of 18.60% (weight of 172 kg - 266 kg per plant). These differences in sago starch production are thought to be due to variations in growing conditions and different environments. Thus, sago production in the Sentani watershed can still be increased through good forest management, such as drainage regulation and thinning.

Table 4. The individual density and volume of sago plants on different habitat types in Sentani watershed, Jayapura District, Papua, Indonesia

Sago variety	Habitat type: Dryland		Temporarily flooded		Prolonged flooded		Average	
	Individual ($ind.ha^{-1}$)	Volume (m^3ha^{-1})	Individual ($ind.ha^{-1}$)	Volume ($m^3.ha^{-1}$)	Individual ($ind.ha^{-1}$)	Volume ($m^3.ha^{-1}$)	Individual ($ind.ha^{-1}$)	Volume ($m^3.ha^{-1}$)
Ebhesum	-	-	1	2.00	-	-	0.3	0.67
Folo	2	2.34	1	1.36	1	1.35	1.3	1.68
Hobholo	1	1.68	-	-	-	-	0.3	0.56
Manno	1	1.65	2	2.69	-	-	1.0	1.45
Phane	-	-	1	1.20	-	-	0.3	0.40
Phara	3	4.77	2	3.81	1	1.57	2.0	3.38
Rondo	2	2.20	2	3.37	-	-	1.3	1.86
Ruruna	1	1.17	-	-	1	1.59	0.7	0.92
Osukhulu	1	1.57	2	3.23	-	-	1.0	1.60
Wani	-	-	1	2.30	-	-	0.3	0.77
Yakhalobe	-	-	1	2.17	-	-	0.3	0.72
Yakhe	-	-	1	2.01	1	1.07	0.7	1.03
Yebha	1	1.96	2	2.61	-	-	1.0	1.52
Total	12	17.34	16	26.74	4	5.58	10.7	16.55
Average	0.92	1.33	1.23	2.06	0.31	0.43		

Table 5. Starch production of sago varieties in Sentani watershed, Jayapura District, Papua

Sago variety	Height (m)	Diameter (cm)	Starch production: Vol (m^3)	Wet (kg)	Dry(kg)	Subdistrict
Ebhesum	13.0	50.20	23.15	221.63	166.14	Sentani, and West Sentani
Folo	15.2	48.47	25.23	281.12	215.55	Ebungfau, Sentani, West Sentani, East Sentani, Waibu
Hobholo	13.1	45.00	18.74	204.91	153.91	Sentani and Waibu
Manno	9.8	38.41	10.21	54.39	45.40	Ebungfau, Kemtuk, Sentani, West Sentani, East Sentani, Waibu
Phane	12.2	47.21	19.21	184.06	144.55	Sentani, and East Sentani
Phara	15.6	50.27	27.85	292.55	224.89	Ebungfau, Sentani, West Sentani, East Sentani, Waibu
Rondo	10.7	50.87	19.56	163.50	128.43	Ebungfau, Sentani, West Sentani and East Sentani,
Ruruna	14.0	49.47	24.21	248.81	196.17	Ebungfau, Sentani, and Waibu
Osukhulu	13.6	48.37	22.48	209.85	170.68	Sentani and Waibu
Wani	11.7	42.55	14.97	126.16	100.04	Sentani and East Sentani
Yakhalobe	11.2	48.61	18.70	114.24	143.78	Ebungfau, Kemtuk, and Sentani
Yakhe	12.0	46.52	18.35	118.92	96.95	Kemtuk and Sentani
Yebha	16.0	51.17	29.60	313.20	235.87	Ebungfau, Sentani, West Sentani,dan East Sentani
Average	12.9	47.50	20.56	194.90	155.60	

Table 6. Sago production potentials based on habitat types in the Sentani watershed Jayapura District, Papua, Indonesia

Sago production parameters	Starch production potentials (tons/year)						Total
	Ebungfau	Kemtuk	Sentani	West Sentani	East Sentani	Waibu	
Dryland habitat (ha)	150.72	221,20	13.33	435.75	44.27	381.08	1,246.35
Sago varieties (var)	6	3	10	5	5	6	35
Mature plants (ind.ha^{-1})	10	3	12	9	9	9	52
Starch yield (kg/plant)	225.60	95.85	221.04	220.95	220.95	215.57	1,199.96
Total production (tons.year^{-1})	340.02	63.61	35.36	866.51	88.03	739.34	2,132.88
Temporarily flooded habitat (ha)	522.24	372.10	1,728.76	260.26	901.20	1035.93	4820,49
Sago varieties (var)	6	3	13	6	7	4	39
Mature plants (ind.ha^{-1})	10	4	16	10	11	7	58
Starch yield (kg/plant)	203.17	95.85	189.06	221.07	202.14	209.48	1,120.77
Total production (tons.year^{-1})	1,061.04	142.66	5,229.43	575.36	2003.85	1519.05	10,531.39
Prolonged flooded habitat (ha)	226.57	-	422.52	-	576.38	550.45	1,775.92
Sago varieties (var)	7	-	8	-	2	3	20
Mature plants (ind.ha^{-1})	3	-	4	-	2	3	12
Starch yield (kg/plant)	274.16	-	216.30	-	286.84	274.16	1,051.46
Total production (tons.year^{-1})	186.35	-	365.56	-	330.66	452.73	1,335.31
Sum 1 + 2 + 3	1,587.41	206.27	5,630.35	1,441.87	2,422.55	2,711.13	13,999.57

The production potential of sago plants all over the Sentani watershed is estimated 13,999.57 tons.year^{-1}. The plant can provide sufficient food sources for the community in the coastal and lowland areas of Papua as a source of carbohydrates (Hasibuan et al. 2018). The highest and lowest production is found in Sentani and Kemtuk Sub-districts at 5,630.35 tons.year^{-1} (40.22%) and 1,587.41 tons.year^{-1} (1.47%), respectively. The potential starch production is determined based on the number of mature plants and starch content per plant. Sago plant with long, round, and large diameter stem usually have high starch production, which correlates positively with stem weight and starch content in the stem (Ehara et al. 2018). The sago production potential based on habitat types can be seen in Table 6.

The dryland habitat has a total starch production potential of 2,132.88 tons.year^{-1} (15.24%) with the highest and lowest in West Sentani and Sentani Sub-districts at 866.51 tons.year^{-1} (6.19%) and 35.36 tons.year^{-1} (0.25%), respectively. The average number of mature plants is 8 individuals per ha with an average wet starch yield of 199.99 kg per plant. The temporarily flooded habitat has a total starch production of 10,531.39 tons.year^{-1} (75.23%) with the highest and lowest in Sentani and Kemtuk Sub-districts at 5,229.43 tons.year^{-1} (37.35%) and 142.66 tons.year^{-1} (1.02%), respectively. The average number of mature plants is 9 individuals per ha with an average wet starch yield of 186.80 kg per plant. The temporarily flooded habitat, covering an area of 4,820.49 ha, is suitable for 13 varieties. In the prolonged flooded habitat, the total sago production reaches 1,335.31 tons.year^{-1} (9.54%) with the highest and lowest in Waibu and Ebungfau Sub-districts at 452.73 tons.year^{-1} (3.23%) and 186.35 tons. year^{-1} (1.33%), respectively. Meanwhile, Kemtuk and West Sentani Sub-districts do not have sago forests in the prolonged flooded habitat. The average number of mature plant is 3 individuals per ha with an average wet starch yield of 175.24 kg per plant.

In conclusion, the areas covered with sago plants in the Sentani Watershed are estimated 7,842.76 ha, distributed across the Ebungfau, Kemtuk, Sentani, West Sentani, East Sentani, and Waibu Sub-districts. The species *Metroxylon sagu* Rottb in this region is divided into 13 local varieties according to the Sentani language, namely *ebhesum, folo, hobholo, manno, phane, phara, rondo, ruruna, osukhulu, wani, yakhalobe, yakhe*, and *yebha*. There are 8, 11, and 4 varieties found in the dryland, temporarily flooded and prolonged flooded habitats. *Yebha* and *phara* have the highest potential for wet starch production, reaching 313.20 kg and 292.55 kg, respectively. Meanwhile, the lowest production is obtained by *manno* variety at 54.39 kg. The dryland habitat contains 12 mature plants per ha and a total starch production of 2,132.88 tons.year^{-1}, with the highest in West Sentani Sub-district at 866.51 tons.year^{-1}. Furthermore, the temporarily flooded habitat consists of 16 mature plants per ha and a total production of 10,531.39 tons.year^{-1}, with the highest in Sentani Sub-district at 5,229.43 tons.year^{-1}. The prolonged flooded habitat contains 4 mature plants/ha and a total sago production of 1,335.31 tons.year^{-1}, with the highest found in the Waibu Sub-district at 452.73 tons.year^{-1}. Kemtuk and West Sentani Sub-districts do not have sago forests in the prolonged flooded habitat. The sago production potential across the Sentani Watershed is estimated 13,999.57 tons. year^{-1}. Our findings suggest that two sago varieties, namely *phara and yebha*, are recommended for cultivation because they are more adaptive and have high starch yield compared to other sago varieties.

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REFERENCES

Abbas B, Ihwan T, Munarti. 2020. Genetic diversity of sago palm (*Metroxylon sagu*) accessions based on plastid cpDNA matK gene as DNA barcoding. Biodiversitas 21 (1): 219-225. DOI: 10.13057/biodiv/d210128.

Anugoolprasert O, Shina K, Hitoshi N, Masafumi S, Hiroshi E. 2012. Effect of low pH on the growth, physiological characteristics and nutrient absorption of sago palm in a hydroponic system. Plant Prod Sci 15 (2): 125-131. DOI: 10.1626/pps.15.125.

Arland S, Emy S, Muhammad I. 2018. Studi penerapan metode pohon contoh (*tree sampling*) dalam pendugaan potensi tegakan hutan tanaman ekaliptus. Wahana Forestra Jurnal kehutanan 13 (2): 132-143. DOI: 10.31849/forestra.v13i2.1567.

Azhar A, Daigo M, Hitoshi N, Hiroshi E. 2018. Photosynthesis of sago palm (*Metroxylon sagu* Rottb.) seedlings at different air temperatures. Agriculture 8: 4. DOI: 10.3390/agriculture8010004.

Azhar A, Daigo M, Hitoshi N, Hiroshi E. 2020a. Evaluating sago palm (*Metroxylon sagu* Rottb.) photosynthetic performance in waterlogged conditions: Utilizing pulse-amplitude modulated (PAM) fluorometry as a waterlogging stress indicator. J Saudi Soc Agric Sci 19 (1): 37-42. DOI: 10.1016/j.jssas.2018.05.004.

Azhar A, Daigo M, Hitoshi N, Koki A, Mai T, Saeka U, Rena T, Barahima A, Hiroshi E. 2020b. Sago palm (*Metroxylon sagu* Rottb.) response to drought condition in terms of leaf gas exchange and chlorophyll a fluorescence. Plant Prod Sci 24: 1-8. DOI: 10.1080/1343943X.2020. 1794914.

Bujang K. 2018. Production, Purification, and Health Benefits of Sago Sugar. In: Ehara H, Toyoda Y, Johnson DV (eds). Sago Palm: Multiple Contributions to Food Security and Sustainable Livelihoods. Springer Nature, Singapore.

Crausbay SD, Martin PH. 2016. Natural disturbance, vegetation patterns and ecological dynamics in tropical montane forests. J Trop Ecol 32: 384-403. DOI: 10.1017/S0266467416000328.

Dimara PA, Purwanto RH, Sunarta S, Wardhana W. 2021. The spatial distribution of sago palm landscape Sentani watershed in Jayapura District, Papua Province, Indonesia. Biodiversitas 22 (9): 3811-3820. DOI: 10.13057/biodiv/d220926.

Dimara PA, Auri A. 2023. Effect of landform on the distribution of *Metroxilon sagu* habitat in Yapen Island, Papua Province, Indonesia. Jurnal Sylva Lestari 11 (1): 79-97. DOI: 10.23960/jsl.v11i1.633.

Dewi RK, Bintoro MH, Sudrajat. 2016. Morphological characteristics and yield potential of sago palm (*Metroxylon* spp.) accessions in South Sorong District, West Papua. J Agron Indonesia 44: 91-97. DOI: 10.24831/jai.v44i1.12508.

Ehara H, Toyoda Y, Johnson DV. 2018. Sago palm: Multiple Contributions to Food Security and Sustainable Livelihoods. Springer Nature, Singapore.

Fathnoer V, Bintoro MH, Iskandar L. 2020. Assessment of morphological attributes of sago palm accessions of Aimas, Sorong, West Papua, Indonesia. J of Tropical Crop Sci 7: 7-13. DOI: 10.29244/jtcs.7.01.7-14.

Hasibuan HS, Waromi LF, Utomo SW. 2018. Sustainable food security strategy: Study of land suitability of rice and sago commodity in Kampong Wapeko, Merauke District, Papua Province, Indonesia. E3S Web Conf 68: 04008. DOI: 10.1051/e3sconf/20186804008.

Hussain H, Kamal MM, Al-Obaidi JR, Hamdin NE, Ngaini Z, Yusuf YM. 2019. Proteomics of sago palm towards identifying contributory proteins in stress-tolerant cultivar. Protein J 39 (1): 62-72. DOI: 10.1007/s10930-019-09878-9.

Konuma H. 2018. Status and Outlook of Global Food Security and the Role of Underutilized Food Resources: Sago Palm. In: Ehara H, Toyoda Y, Johnson DV (eds). Sago Palm: Multiple Contribution to Food Security and Sustainable Livelihoods. Springer Open, Tokyo.

Lim LWK, Chung HH, Hussain H, Bujang K. 2019. Sago palm (*Metroxylon sagu* Rottb.): now and beyond. Pertanika J Trop Agric Sci 42 (2): 435-451.

Lim LWK, Chung HH. 2020. Salt tolerance research in sago palm (*Metroxylon sagu* Rottb.): Past, present and future perspectives. Pertanika J Trop Agric Sci 43 (2): 91-105.

Lilleleht A, Sims A, Pommerening A. 2014. Spatial forest structure reconstruction as a strategy for mitigating edge-bias in circular monitoring plots. For Ecol Manag 316: 47-53. DOI: 10.1016/j.foreco.2013.08.039.

Louhenapessy JE, Luhukay M, Talakua S, Salampessy H, Riry J. 2010. Sagu: Harapan dan Tantangan. Bumi Aksara, Jakarta. [Indoesian]

Matanubun H. 2015. Folk Taxonomy of Sago Palm Varieties Around Sentani Lake, Jayapura, Papua Province, Indonesia. Proceedings of the 12th International Sago Symposium. Manokwari, 15-16 September 2015.

Miyazaki A, Tetsushi Y, Yoshinori Y, Yayoi C, Fransiscus SR, Yulius BP, Foh Shoon J. 2011. Effect of plant aging on root development of sago palm (*Metroxylon sagu* Rottb.) grown in Tebing Tinggi Island, Riau Province and in Kendari, Southeast Sulawesi in Indonesia. Trop Agric Develop 55 (3): 103-107. DOI: 10.11248/jsta.55.103.

Miyazaki A, Watanabe D, Yamamoto Y, Yoshida T, Rembon FS, Pasolon YB, Jong FS. 2016. Comparison of root development in sago palm of different ages, regions and folk varieties. Trop Agric Develop 60: 179-184. DOI: 10.11248/jsta.60.179.

Muhidin, Sitti L, Syamsu A. Teguh W. 2016. Comparative studies on different agroecosystem base on soil physicochemical properties to development of sago palm on dryland. Intl J Chem Technol Res 9 (08): 511-518.

Morrison C, Isaac R, Dick W. 2012. Conservation and management of the endangered fiji sago palm, *Metroxylon vitiense*, in Fiji. Environ Manag 49: 929-941. DOI: 10.1007/s00267-012-9836-3.

Normand AE, Smith AN, Clark MW, Long JR, Reddy KR. 2017. Chemical composition of soil organic matter in a subarctic peatland: Influence of shifting vegetation communities. Soil Sci Soc Am J 81: 41-49. DOI: 10.2136/sssaj2016.05.0148.

Okazaki M, Kimura SD. 2015. Ecology of the Sago Palm. In: The Sago Palm: The Food and Environmental Challenges of the 21st Century; The Society of Sago Palm Studies. Kyoto University Press, Kyoto.

Riyanto R, Imam W, Barahima A. 2018. Morphology, growth and genetic variations of sago palm (*Metroxylon sagu* Rottb) seedlings derived from seeds. Biodiversitas 19: 682-688. DOI: 10.13057/biodiv/d190241.

USGS [United States Geological Survey]. 2017. Landsat Collection 1 Level 1 Product Definition In: Survey, D.o.t.I.U.S.G. (Ed.). USGS, Sioux Falls, South Dakota, USA.

Yamamoto Y, Tetsushi Y, Isamu Y, Febby JP, Willem AS, Foh Shoon J, Yulius BP, Akira M, Tomoko H, Kazuko H. 2020a. Studies on growth characteristics and starch productivity of the sago palm (*Metroxylon sagu* Rottb.) folk varieties in Seram and Ambon Islands, Maluku, Indonesia. Trop Agric Develop 64 (3): 125-134. DOI: 10.11248/jsta.64.125.

Yamamoto Y, Kazuo K, Tetsushi Y, Akira M, Foh Shoon J, Yulius BP, Hubertus M, Fransiscus SR, Nicholus, Jermia L. 2020b. Growth characteristics and starch productivity of folk varieties of sago palm around Lake Sentani near Jayapura, Papua State, Indonesia. Trop Agric Develop 64: 23-33. DOI: 10.11248/jsta.64.23.

Yamamoto Y, Kazuo K, Tetsushi Y, Akira M, Foh Shoon J, Yulius BP, Hubertus M, Fransiscus SR, Nicholus, Jermia L. 2020c. Changes in leaf and trunk characteristics related to starch yield with age in two sago palm folk varieties grown near Jayapura, Papua, Indonesia. Trop Agric Develop6 4 (2): 61-71. DOI: 10.11248/jsta.64.61.

Yater T, Herman WT, Cipta M, Baharima A. 2019. A comparative study of phenotypes and starch production in sago palm (*Metroxylon sagu*) growing naturally in temporarily inundated and noninundated areas of South Sorong, Indonesia. Biodiversitas 20 (4): 1121-1126. DOI: 10.13057/biodiv/d200425.