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Evaluation and Development of Sago Palm as a Natural Starch Resource in the Tropics

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Introduction

More than 40 years have passed since the First International Sago Symposium was held in Kuching in 1976. During this period, an international sago symposium was convened every 2–6 years. At the symposia, many research results related to the sago palm and sago starch, as well as the social aspects of the sago palm in the local community, have been reported. Moreover, many research results were submitted to various journals, and some were also published in a book, *The Sago Palm*, by the Society of Sago Palm Studies of Japan, in 2015. However, the sago industry, especially plantation development, processing, and marketing, are lagging terribly behind their potential (Jong, 2015).

In this paper, first, I would like to clarify to what extent we have already studied the characteristics of sago palm, such as growth environment and starch productivity per individual palm and per area basis. Second, I try to describe the characteristics of the sago palm from the viewpoints of adaptation to climate change, agronomic traits, and food safety and security to consider the sago palm as an important starch crop in the Tropics in the future. Third, I mention the starch supply and demand in the world to clarify the role of the sago palm as a starch resource in the Tropics. Finally, I would like to propose my ideas for the development of sago palm research, as well as sago starch production and utilization for the future.

1. Characteristics of the sago palm

1) Growth environment

The sago palm (*Metroxylon sagu* Rottb.) is indigenous to the lowlands of Southeast Asia and Melanesia, located between latitudes 10°N and 10°S, to an altitude of 700 m (Flach, 1977; Rasyad and Wasito, 1986). Sago palms can grow under a wide range of environments, except drought. It has some tolerance to salt and flooded soil conditions. Sago palms are growing at the seaside on Tebing Tinggi Island, Riau, Indonesia (Yamamoto et al., 2003a), and flood-prone areas in Indonesia, Malaysia, Papua New Guinea, etc. Sago palms can grow in various types of soil, including peat soil (Sato et al., 1979). It has been said that the sago palm is the only crop that can grow in deep peat soil without any management. However, Yusuf et al. (2015) recently concluded that the sago palm cannot grow well in peat soil more than 5 m deep even with enough fertilizer applied. This implies the need for further detailed studies on the effects of peat soil on the growth and yield of sago palms in relation to the type and deepness of peat soil. There are few reports on sago palms growing at higher elevations. Sasaoka (2006, 2007) reported sago palms growing at the mountainous area, around 730 m elevation, on Seram Island, Maluku Province, Indonesia. The starch productivity of sago palms at high elevations should be clarified to consider the introduction of sago palms to these areas for food safety and security in the future.

2) Starch productivity

(1) Starch productivity of individual palms

The starch productivity of individual sago palms varied greatly—almost 0 to 1000 kg dry starch—by regions and/or folk varieties (hereafter, variety) (Yamamoto, 2015a). Wild-type sago palms growing in the presumed area of origin showed low starch content due to suspected less efficient processes of synthesizing starch from sugars (Yanagidate et al., 2009). Moreover, sago palms growing in natural sago forests showed higher water percentages in the pith (Yamamoto, 2016). The starch productivity of cultivated sago palms is mainly determined by the biomass produced until harvesting (flower bud formation to the flowering stage), but not by differences in the ratios of dry matter distribution to the harvested portion (pith) or starch percentage in the pith (Yamamoto, 2015b; Yamamoto et al., 2016). The biomass is mainly determined by the leaf area per palm, and the differences in leaf area per palm among the varieties are determined by the differences in leaf area per leaf caused by differences in the leaflet width (Yamamoto et al., 2014; 2016). The growth duration from trunk formation to harvesting also affects the starch yield through the biomass production (Yamamoto, 2011).

Starch productivity is also affected by environmental conditions, such as soil types, underground water levels, sea water invasion, and elevation. Although Yusuf et al. (2015) reported the impossibility of cultivating sago palms as an economic crop in peat soil more than 5 m deep, some researchers have reported that the starch productivity of sago palms grown in deep peat soil were comparable to that of those grown in mineral soil (Sim and Ahmed, 1978; Kueh et al., 1991; Yamamoto et al., 2003b).

Sago palms can tolerate flood water during monsoon season in Southeast Asia and Melanesia, but it cannot form trunk under deep water throughout the year. The sago palm tolerates sea water invasion, to some extent, and this mechanism has been clarified by Ehara et al. (2006, 2008). Sago palms at the seaside of Tebing Tinggi Island showed greatly inferior growth and starch yield as compared to those growing more than 100 m from the sea, although the starch percentage in the pith was comparable to that of palms growing inland (Yamamoto et al., 2003a). Sago palms growing at elevations over 730 m showed slightly thicker diameters and slightly shorter statures, as compared to those growing in lowlands (Sasaoka, 2006; 2007). The starch content in the pith of sago palms growing at higher elevation may be lower than that of those growing in lowlands.

Cultivation management, such as thinning suckers, water management, fertilizer application, weeding, etc., may strongly affect the growth and starch yield of sago palms, but there are few reports related to these factors. Under high density conditions without thinning, trunks grew longer, but the diameter became slender (Yamamoto, 2015a), and starch percentages in the pith were also lower in these palms. It takes a long time to clarify the effects of cultivation management on growth and starch yields, but it is essential for establishing a sago plantation with sustainable and stable production in the future. Regarding sucker management, Nakamura et al. (2015) and Nabeya et al. (2015) analyzed the growth patterns of sago palm suckers after transplanting.

Regarding the starch productivity of sago palms, it is important to recognize the differences in starch yield by different extraction methods. Chemical analysis showed that, as compared to 100% starch extraction efficiency when using acid such as perchloric acid, extraction efficiency was about 80% and about 50% when using the electric blender and the traditional extraction method, respectively (Miyazaki et al., 2006; Schuiling, 2006; Yamamoto et al., 2007).

(2) Starch productivity of sago palm per land area

As compared to research data regarding the starch yield of individual palms, there are few reports regarding the starch productivity per land area. One reason for the limited research on starch productivity per land area of sago palms may be that sago palms grow in a scattered fashion, and it is difficult to find appropriate sites with uniform palm density. Following the quadrat method and counting and measuring the length of all trees that have formed trunks, Osozawa (1990), Yamamoto et al. (2008), and Yanagidate et al. (2009) reported changes in the starch yield per ha over time at a few sago palm gardens in Luwu, South Sulawesi; Tebing Tinggi Island, Riau; and Kendari, Southeast Sulawesi Indonesia, respectively. According to the data obtained, the starch yield (by chemical analysis) per ha ranged from 4.5 to 13.5 tons (average: 9 tons) per year in South Sulawesi and from 1.4 to 22.2 tons (average: 10.2 tons) per year in Riau. The results clearly showed that if suckers were not well controlled, it would be very difficult to achieve sustainable and stable starch production, and the yield gradually decreased with years of harvesting. These results also clearly show the importance of managing sago gardens or plantations for sustainable and stable starch production.

Regarding the potential starch yield, Flach (1980) estimated about 25 t/ha/year when 50% of palms are harvestable per year, at a planting density of 6 m x 6 m (277 palms/ha), and the average starch yield per palm is 185 kg. On the other hand, applying the starch yield data of individual palms obtained (100–800 kg), Yamamoto (2006) calculated the starch yield per ha by combining the number of harvestable palms per ha, the total number, and 1/2 and 1/3 at densities of 8 m x 8 m and 10 m x 10 m, respectively, that is 33–156 palms/ha, and estimated the range of the realizable starch yield of sago palms as being 3.3–124.8 t/ha/year. Considering the reduction of the harvestable number of palms when the individual palm starch yield is increased, he estimated the potential yield to be 25–40 t/ha/year.

(3) Sago starch productivity as compared with that of other starch crops

The starch productivity of the sago palm was compared with that of other major cereal, root, and tuber crops (Yamamoto, 2015a) (Table 1). For the major crops, the world average yields from FAOSTAT 2012 are quoted. The starch yields of these crops were calculated by multiplying the average yield and the starch percentage. For the sago palm, Cases A, B, and C indicate reasonable starch yields per palm of 100, 200, and 300 kg, respectively. The starch yields were calculated by multiplying the yield per palm and the number of harvestable palms per ha per year, 30 or 50 palms. These numbers are equivalent to one-third and half of the total number of clumps planted in a 10 m x 10 m square. The results suggest that the starch yield of

Table 1. Comparison of starch yield of sago palm with that of major cereal, root and tuber crops.

Crop	World average yield[1] (t/a)	Water content (%)	Starch[4] (%)	Starch yield (t/ha)
Rice	4.41[2] (3.09)[3]	15.5	73.8	2.28
Wheat	3.11	13.0	69.4	2.16
Maize	4.92	14.5	70.6	3.47
Cassava	12.88	70.3	30.0-33.3	3.9-4.3
Sweet Potato	12.75	66.1	15.0-30.0	1.9-3.8
Potato	19.00	75.8	10.0-30.0	1.9-5.7

Sago palm	Starch yield (kg/palm)	No. of harvestable palms (/ha)	Starch yield (t/ha)
Case A	100	30	3.0
		50	5.0
Case B	200	30	6.0
		50	10.0
Case C	300	30	9.0
		50	15.0

1) FAOSTAT (2012). 2) Paddy yield. 3) Brown rice yield (paddy yield x 0.7). 4) Rough value.
Source; Yamamoto (2015).

the sago palm is considerably higher than those of major cereal, root, and tuber crops.

2. Sago palm's tolerance of climate change and its role in food safety and security

The agronomic characteristics of the sago palm as a starch-accumulating palm were compared with those of cereal, root, and tuber crops (Table 2). Stems (trunks) are utilized in starch accumulation, and the palms are propagated by seed or sucker. Also, the input and techniques for cultivating, harvesting, and postharvest processing are lower and easier, as compared to those of cereal crops. Moreover, the storage ability of starch after drying is as high as in cereals.

Figure 1 shows a comparison of the tolerance of starch crops to transient heat, droughts, floods, etc., that have occurred frequently with climate change in recent years. It is presumed that in cereals, crops are particularly sensitive during the flowering and ripening period, and in root and tuber crops, crops are susceptible to these transient changes of the meteorological environments during the tuberous root/tuber formation and developmental period. In cereals, when these transient meteorological environments are encountered during the flowering period, fertilization is unsuccessful, to various degrees; consequently, yields are partially reduced, or there is no harvest. Meanwhile, such an encounter at the ripening stage results in the early termination of ripening and poor maturity, resulting in a decreased yield. In root

Table 2. Agronomical characteristics of starch crops

Crop	Part for utilization	Reproductive system	Input and teqhnique for cultivation	Harvest and preparation
Cereals	Fruit (seed)	Seed	High	Complicated
Root and tuber	Root, Tuber	Root, Tuber	Medium	Medium
Sago palm	Stem (trunk)	Sucker, Seed	Low	Easy

Crop	Pest and disease	Storage ability	Harvesting time
Cereals	Serious	High	Seasonal
Root and tuber	Serious	Low	Seasonal
Sago palm	Rare	High	Non-seasonal

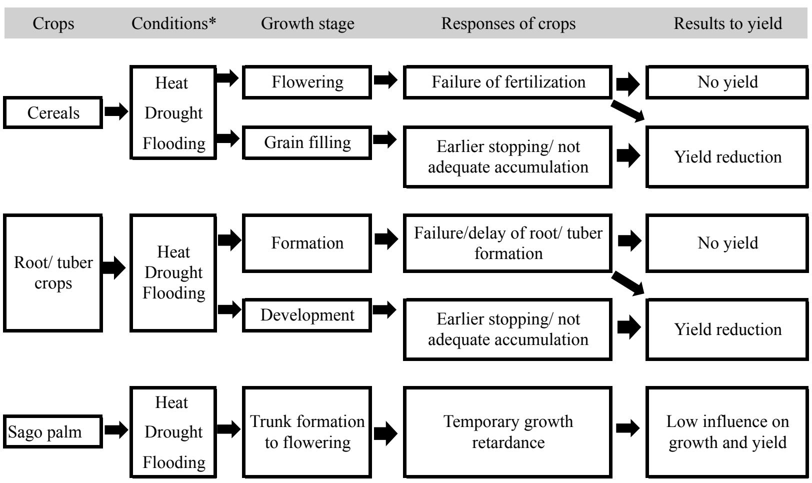

Fig 1. Comparison of tolerability of starch crops to the climate change
*Transient defective meteorological conditions due to climate change.

and tuber crops, when these defective environments are encountered during the tuberous root/tuber formation period, harvesting is lost or yield is reduced, depending on the retardation and/or degree of formation of the starch storage structure. An encounter during the growth period of tuberous roots/tubers causes low yields due to the early stoppage of starch accumulation and poor accumulation.

As compared to these cereals, roots, and tuber crops, the sago palm's development of the stem (trunk), which is a starch accumulation organ, is little influenced by these transient defective environments. It is estimated that encounters with these defective environments during the starch accumulation period only result in a reduction of starch accumulation for a very short period, as compared to the length of the growing period (from trunk formation and flowering). Therefore, the influence on the final starch yield is small. In other words, the sago palm is considered to be more tolerant of transient defective environments due to climate change than are general annual starch crops. Therefore, much more attention should be paid to the sago palm from the viewpoint of food safety and security in the Tropics.

Next, I tried to consider how many people sago palm can support as an energy supplier as compared with rice (Table 3). For rice, I show the world average paddy yield from FAOSTAT 2012. The average yield (4,410 kg per ha) was converted to the milled rice yield, and the calorie production per ha was calculated using the calorie per 100 g of milled rice (356 kcal) (Kagawa, 2001). The calorie production per ha was divided by the roughly estimated minimum calorie intake per capita per day (2000 kcal) (UNHCR and WFP, 1997; MAFF 2018) determined to support the population per ha per day. The value is 4,945 for rice. For sago palm, the starch yield per ha was calculated in the same way as mentioned above, that is, combining the starch yield per palm for 100, 200, and 300 kg and the number of harvestable palms per ha, 30 or 50 palms. The starch yield ranged from 3 to 15 ton per ha, and the calorie production per ha was calculated by multiplying the starch yield and calorie per 100 g starch (349 kcal) (Kagawa, 2001). Then, following the same method in rice, we calculated the supporting population per ha per day. As compared to rice (world average yield), the sago palm can support more people in any case, with ratios ranging from 1.06–5.29.

These characteristics and estimations of sago palm suggest that it should be considered as a promising candidate for a supplementary food crop (energy supplier) in the humid tropical countries for food safety and security as well as a promising industrial starch crop.

3. Role of sago starch in the starch market and problems as a starch supplier

The world starch production in 2015 was 38.465

Table 3. Number of peoples can be supported by rice and sago palm

Rice

World	Paddy yield[1] (kg/ha)	Brown rice[2] (kg/ha)	Starch yield[3] (kg/ha)	Milled rice[4] (kg/ha)	Calorie of MR[5] (Kcal/100g)	Calorie production (Kcal/ha)	Calorie intake (Kcal/capita/d.)	Supporting Pop. (No./ha./d.)
World Avg.	4,410	3,087	2,161	2,778	356	9,889,680	2,000	4,945

1) FAOSTAT (2012). 2) Paddy yield x 0.7. 3) Brown rice yield x 0.7. 4) Brown rice yield x 0.9. 5) Kagawa (2001).

Sago palm

Starch yield (kg/palm)	No. of harvestable palms (No./ha)	Starch yield (kg/ha)	Calorie[1] (Kcal/100g)	Calorie production (Kcal/ha)	Calorie intake (Kcal/capita/d.)	Supporting Pop. (No./ha/d.)	Supporting ratio (sago/rice)
100	30	3,000	349	10,470,000	2,000	5,235	1.06
	50	5,000	349	17,450,000	2,000	8,725	1.76
200	30	6,000	349	20,940,000	2,000	10,470	2.12
	50	10,000	349	34,900,000	2,000	17,450	3.53
300	30	9,000	349	31,410,000	2,000	15,705	3.18
	50	15,000	349	52,350,000	2,000	26,175	5.29

1) Kagawa (2001).

million tons. Corn, cassava, potatoes, wheat, and miscellaneous crops, including sago palm starch, contributed 43.8, 22.8, 4.6, 4.3, and 1.9%, respectively, of the total production (Agriculture and Livestock Industries Corporation 2016b) (Table 4). Twenty-one percent of the total starch production was contributed by processed starch. Of these starches, 90% of cassava starch was produced in Asia, especially in Southeast Asian countries such as Thailand, Vietnam, and Indonesia. However, there are worries about stable cassava starch production in Southeast Asia due to unstable meteorological conditions and the risk of outbreak of pests and diseases in the near future. On the other hand, world starch consumption is anticipated to increase at a rate of 2.5–3.5% per year in the medium term and comes to a total of 5.5 million tons from 2014 through 2019 (Agriculture and Livestock Industries Corporation, 2016a) (Table 4). Starch prices for exporting are higher in the order of processed starch>potato>corn≒wheat>cassava starch, and the price is greatly affected by the material price as compared with the balance of supply and demand (Agriculture and Livestock Industries Corporation, 2016a).

Sago starch has been mainly produced in Malaysia and Indonesia, but most of it was consumed in their countries of origin, and only a small amount of sago starch was traded internationally. For example, about 60,000 tons of sago starch were produced per year in Malaysia, mostly in Sarawak, and about 20,000 tons were exported to Japan, Singapore, etc. Sago starch is mainly used to produce vermicelli (thin pasta), biscuit, material for saccharification, sodium glutamate, cosmetics, etc. (Agriculture and Livestock Industries Corporation 2012). In Cirebon, Indonesia, there are around 60 sago noodle (*Sohun*) factories that imported 110,000–170,000 tons of sago starch per year from Riau (Yamamoto et al., 2010). In Japan, sago starch is mainly used as a dusting flour for noodles such as *udon*, *ramen*, and *soba* or dumpling skins such as *gyoza* and *shumai* (Kondo, 2015).

As the starch characteristics of sago palm are similar to those of cassava starch, except amylose content and retrogradation (Kainuma, 2015), stable and considerable amounts of starch production with improved quality are essential if sago palm starch is to enter into the global starch market more strongly in the future. Currently, sago starch has been mainly produced by small-scale factories in Indonesia and Malaysia, and a large-scale sago factory with a sago palm plantation has not completely succeeded. Because of this situation, the quality of sago starch is still variable, as compared with other natural starches. Regarding the starch productivity of the sago palm, natural sago forests in Papua and West Papua States in Indonesia and in Papua New Guinea may have high

Table 4. Changes in starch production and consumption of each kind of starch.

Starch	Production (1000t)				Consumption (1000t)			
	2013	2014	2015	Fluctuation ratio (%)*	2013	2014	2015	Fluctuation ratio (%)*
Corn	16,787	16,533	16,847 (43.8)	1.9	16,787	16,527	16,852	2.0
Tapioca	8,443	8,801	8,771 (22.8)	-0.3	8,444	8,803	8,773	-0.3
Potato	1,549	1,620	1,786 (4.6)	10.3	1,549	1,620	1,787	10.3
Wheat	1,476	1,596	1,655 (4.3)	3.7	1,484	1,601	1,670	4.3
Others	671	713	725 (1.9)	1.7	671	728	737	1.2
Processed	7,919	7,927	8,092 (21.0)	2.1	7,919	7,927	8,092	2.1
Glue/ Adhesive	545	570	590 (1.5)	3.5	546	570	590	3.6
Total	37,388	37,758	38,465 (100.0)	1.9	37,399	37,776	38,500	1.9

*Fluctuation percentage to the previous year.

Source; Agriculture and Livestock Industries Corporation (2016) potential, but the development of forests to use in starch production has just started in West Papua State, Indonesia. A constant supply of considerable amounts of sago starch with acceptable quality is the only way to gain a place in the global starch market. At the same time, it is essentially necessary to produce sago starch at a price comparable to or lower than that of cassava starch to be able to compete with it as well as with other natural starches.

4. What can we do to develop sago palm as a natural starch resource in the Tropics?

Jong (2015) reviewed changes in sago starch production and utilization in Malaysia and Indonesia from the 1980s to 2015 in the last (12th) International Sago Symposium held in Japan, concluding that the development and industrialization of sago plantations are terribly behind their potential. To overcome this situation, what can we do to help develop the sago palm as a natural starch resource in the Tropics? Concerning this, I would like to propose the following:

First, we must overcome the constraints encountered in the development of sago palm plantations, as well as sago starch production and utilization through involvement with the International Sago Symposium. The contents of both international and domestic sago symposiums/seminars/workshops should be enriched. In symposiums/seminars/workshops, we should have some subcommittees as well as the usual presentations about solving the various problems in relation to specific issues by involving specialists and the stakeholders.

Second, we need to establish an International Sago Research Center to develop research on topics such as the growth environment, genetics, botany and agronomy, starch properties, and the utilization of sago starch. Such a center could standardize plantation development, cultivation techniques, harvesting and processing techniques, and starch quality. Fostering and training a young generation of researchers and technicians should also be carried out by the Center. Taking into consideration various aspects, such as geographical locations, history of sago palm cultivation and research, and human resources related to sago palms, I would like to recommend Sarawak, Malaysia, as the most appropriate place for the establishment of the International Sago Research Center. I hope that my dream will come true in the future for the development of the sago palm.

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