Chapter 22
Production, Purification, and Health Benefits of Sago Sugar

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Abstract Previous works on the conversion of sago starch and sago hampas into sago sugar, production of cellobiose from sago fronds, and the current studies on the health benefits from consumption of brown sago sugar are presented in this paper. Hydrolysis of sago starch into sugar generates total (100%) recovery, containing glucose (94%), maltose, and other impurities at 3% each. Purification of the brown sago sugar is achieved using powdered activated charcoal to remove all impurities and color. Drying of the purified and concentrated white sago sugar is best performed in an oven (minimum 60 °C), producing high (100%) yield of sugar crystals after several days. Analysis of sweetness revealed that the sago sugar is as sweet as 50% glucose. Brown sago sugar is preferable to white sago sugar due to the presence of antioxidant, analyzed based on total phenolic content (TPC) at 300 mg/kg sugar. Some residual of the TPC can be detected even after purification of the brown sugar. Sago sugar is also obtainable through enzymatic hydrolysis of physically treated sago hampas, generating substantial amount of sugars (70% w/w). Current research also reveals the feasibility of producing cellobiose (approx. 12% w/w) from fresh sago frond, a type of pharmaceutical sugar which commands a higher price than glucose. It is obvious that sago palm has tremendous potential to be adopted as the new source of sugars to replace cane sugar.

22.1 Introduction

In a world starch market dominated by corn, potato, and tapioca, the world production of starch has been estimated to be 27.5 million mt, with an insignificant amount of sago starch consumed, about 3%, 200,000–300,000 mt per annum. Clearly, there is a need to enhance the importance of sago as a major crop in Southeast Asia for global recognition.

The common knowledge about sago is that it thrives in swampy areas or on shallow peat soils without needing copious amounts of pesticides or herbicides

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(Pei-Lang et al. 2006), quite unlike the cultivation of oil palm. Sago is also a hardy palm, only minimally affected by floods and forest fires. More than 90% of all sago-planting areas in Malaysia are found in Sarawak, East Malaysia. Sago is the world's highest starch producer per unit area at 25 mt/ha. This is 4 times higher than rice, 5 times wheat, 10 times potato, and almost 17 times that of tapioca (Ishizaki 1997). Since the average annual intake of starch per person is approximately 250 kg, a 1000 ha sago farm could support and save 100,000 people from starvation (Ishizaki 1997).

The most significant agronomic aspect of sago palm is that it multiplies from suckers; hence replanting is not necessary. The author has had the opportunity to visit a sago field owned by a small community of farmers near Pusa in Sarawak, allegedly planted by their great grandparents, over 300 years ago.

Table sugar is derived from sugarcane, a relatively easy and profitable plant to grow but rather ineffective in reproducing naturally (Braun 1999). On a per capita basis, the amount of sugar consumption in Malaysia is about 50 kg (raw equivalent), one of the highest in the region. Cultivation of sugarcane in Malaysia is relatively small, and although the annual production of sugarcane is relatively high at 1.3–1.6 million mt, the sugar recovery is rather low at only 7–10%/kg of fresh weight.

Lack of local raw materials induces heavy dependency of the sugar industry on imported materials (over 90%). Increases in industrial applications of cane sugar naturally lead to a higher price of this commodity (Adam 2010). Hence, a cheaper alternative which can be obtained locally and in abundance is imperative for sugar production.

22.2 Production of Sugars from Sago Starch

Initial studies on the production of sugars were performed in 1 L lab-scale vessels on hydrolysis of various types of starch (sago, corn, tapioca, and sweet potato flour). A modified procedure for enzymatic hydrolysis of sago starch at the optimum parameters is detailed elsewhere (Bujang et al. 2000a).

Typical enzymatic hydrolysis uses Termamyl-12OL (a thermostable α-amylase from *Bacillus licheniformis*, 120 KNU/g) for liquefaction (0.5 μl/gram of starch) and incubated at 90 °C for 2 h. This is followed by Dextrozyme (a mixture of glucoamylase from *Aspergillus niger* and pullulanase from 225 AGU/ml) for saccharification (0.6 μl/gram of starch) and incubated at 60 °C for another 4–6 h to produce hydrolyzed sago sugars, or HSS (Bujang et al. 2000b; Bujang and Jobli 2002). This period may be extended for larger volumes of hydrolysis (Bujang and Law 2006). This method generates a 100% recovery of glucose from sago starch.

It was confirmed earlier that 20% (w/v) sago starch is the optimum starch concentration (Bujang et al. 2000a, 2004), at the ideal pH of 6.5 for liquefaction and 4.5 for saccharification, for producing sago sugars at over 100% recovery. The same procedure was performed on other types of starch, and, comparatively, the highest concentration of sugars was obtained from sago starch at 100% recovery, followed

by sweet potato (75%), corn (65%), and tapioca starch at 60% (Booty and Bujang 2009).

Increasing the amount of starch from 200 g/L to 10 kg/50 L reduces the glucose recovery by 20%, mostly due to the constraints and capacity of our lab equipment. These results confirmed that it is possible to scale up the process of enzymatic hydrolysis of sago starch with some loss in glucose yield (Booty and Bujang 2009).

22.3 Purification of Sago Sugars

Powdered activated charcoal (PAC) has been used extensively in purification and filtration processes due to its ability to absorb odorous or colored substances from gases or liquids. HSS is centrifuged and filtered to produce brown sago sugar (BSS). Purified sago sugars (PSS), or white sugar, is obtained by PAC filtration of BSS under gravity (2.5 ml/min) which showed a higher (85%) recovery of sugars at a lower amount of PAC (5 g) compared to 10 g PAC (75%). A high recovery of almost 90% was achieved when filtration was enhanced using a pump with a flow rate of 460 ml/h (Bujang et al. 2012).

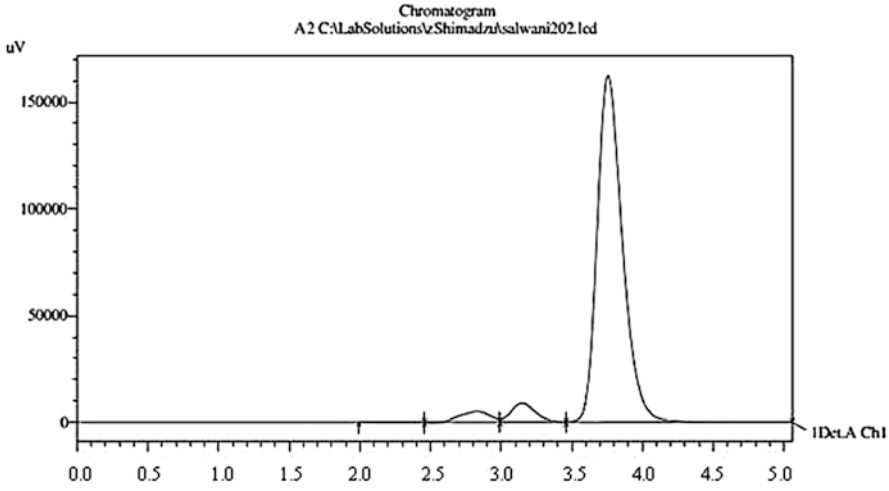
Ang et al. (2006) reported that adsorption between PAC is lower toward glucose and lactate, but higher toward protein and color. However, the purification process to eliminate other impurities will inadvertently adsorb some sugars, albeit at small concentrations. This was amplified when purification was performed at a higher amount of PAC (10 g) where the yield of sugars recovery was lower.

Purified (white) sago sugar contains mostly glucose (94%), with maltose and other impurities, each at 3%, as shown in Fig. 22.1 (Bujang 2012; Monib 2015). The hydrolytic enzymes used contain α-amylase, which attacks gelatinized starch randomly, thereby producing several types of mono- or oligosaccharides as impurities (3%).

22.4 Drying of Sago Sugars

The crystallization of PSS was studied by several methods, freeze drying, spray drying, and oven drying, resulting in different degrees of success and yield. Spray drying gave the lowest recovery at less than 20%, while both freeze drying and oven drying yielded about 100%—all measured based on weight of the dried sago sugars (DSS) at the end of the process.

Although oven drying (60 °C) clearly requires longer time (3–5 days), this method was adopted for our preliminary and future research at lab-scale processes (Monib 2015). However, the heating process creates a slightly yellow color of the sugar crystals.



Detector A Ch1

Peak#	Name	Ret. Time (min.)	Area (mV)	Height (uV)	Conc.	Units
1		2.292	1,661	84	0.000	
2		2.827	81,211	5,283	0.000	
3		3.143	112,629	9,210	0.000	
4		3.752	202,9875	162,435	0.000	
Total			222,5377	177,013		

Fig. 22.1 HPLC analysis of purified or white sago sugar showing maltose and glucose peaks at retention times of 3.1 and 3.7 min, respectively

22.5 Sweetness Test

Sweetness was measured by making a 10–70% solution of the tested compound in distilled water and then requesting a test panel to taste it. If necessary, the solution was diluted and tasted again until the taster could confirm the sweetness (Yau et al. 1989). The relative sweetness of the various sugars or sweetening agents was compared to sucrose at certain dilutions, compared to the sweetness of sucrose as 100 (Godshall 1996).

The sweetness test was performed by dissolving white crystals of sago sugar in water (20 g/L to 100 g/L) and comparing this to a standard solution of 5% sucrose (Godshall 1996), performed by a panel of 15 volunteers. The panelists were required to taste several times—without actually drinking—the sweetness of the standard solution, which is of known concentration, and compared to the test solution. The panelists were then required to record whether one solution was sweeter than the other, or if they are of the same sweetness, in the appropriate column of the score sheet. The tests concluded that white sago sugar (containing 94% glucose) is 50% less sweet than sucrose, which is the main component in cane sugar (Monib 2015).

22.6 Flavonoids in Brown Sago Sugars

Naturally occurring flavonoids have been known to occur in numerous plants. Flavonoids are classified according to their chemical structure and subdivided into three subgroups: (a) flavones; (b) flavan-3-ols, flavan-4-ols, flavan-3,4-diols, and proanthocyanidins; and (c) anthocyanidins. Flavonoids (e.g., catechins) have been shown to be the most common group of polyphenolic compounds in the human diet and are found universally in foods of plant origin.

Preliminary analyses show the part flavonoids play in affecting the role of allergens, viruses, and carcinogens. In vitro studies reveal that flavonoids also have anti-inflammatory (USFDA 2013a), antimicrobial (USFDA 2013b), and anticancer properties (USFDA 2013c). Chemical analyses have been performed on brown sago sugars in order to determine potential benefits from its consumption.

Antioxidant assay is based on total phenolic content (TPC) and total flavonoid content (TFC). TPC analysis (gallic acid standard) was done on brown and white sago sugars. At 20% (w/v), white sago sugar is still much healthier than cane sugar, while brown sago sugar has the highest total phenolic and total flavonoid contents as shown in Table 22.1 (Bujang et al. 2015). The types of flavonoids identified so far in brown sago sugar are gallic acid, quercetin, and kaempferol. Only the latter remains after purification into white sugar. Obviously, the purification process using PAC removed most of the antioxidant properties.

22.7 Production of Sugars from Sago Hampas

Sago hampas is composed of the solids (fibers and vascular bundles) separated by filtration from sago effluent, also a highly potential source of raw material to produce sugar generated by the sago industry (Fig. 22.2a,b). It has been shown that for 1 mt of dried sago starch produced, at least 1 mt of dried hampas is discharged into the river (Bujang et al. 1996).

It was reported earlier that in some older sago mills, sago hampas can harbor as much as 60–70% starch, trapped within its fibers (Abd-Aziz 2002). Fresh hampas also has high moisture content (70–80%) and needs to be dried if it is to be trans-

Table 22.1 Types and amount of flavonoids in cane and sago sugars

Types of sugar (20% w/v)	Total phenolic[1] compound (mg/100 g)	Total flavonoid[2] content (mg/100 g)	Radical scavenging activity (%)
White cane	0.647	0	17
White sago	0.865	0.213	33
Brown sago	39.599	61.064	85

Values are expressed in [1]gallic acid and [2]quercetin equivalent (mg) in every 100 g of glucose

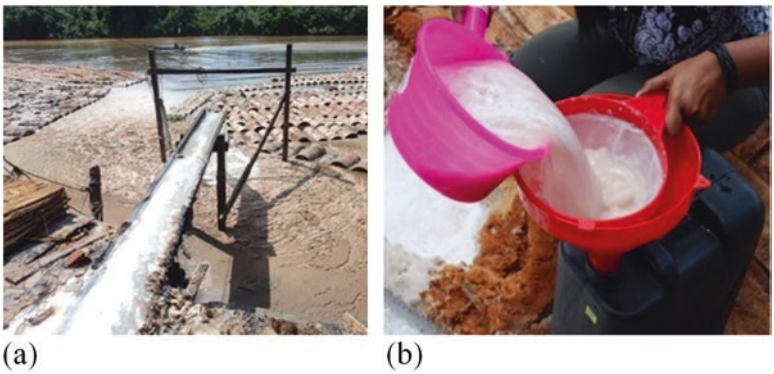


Fig. 22.2 (**a**) A typical view of release of sago effluent into the river. (**b**) Collecting sago hampas by filtering the sago effluent using a normal sieve

Table 22.2 Contents of sago hampas

Composition	% (dry basis)
Starch	30–45
Moisture	5–7
Ash	3–4
Protein	1
Fiber	30–35
Fat	Not detected
pH	4.6–4.7

ported to a processing center. In modern factories, with efficient extraction facilities, waste sago hampas contains less starch (30–45%), as shown in Table 22.2 (Adeni et al. 2009).

Sago hampas has been treated using steam and hydrolyzed using cellulase, β-glucosidase, and an enzyme complex at the optimum concentration of 20 and 1.5% (v/w), respectively. The optimum digestion period was 20 h for cellulase and 16 for β-glucosidase. At the maximum substrate concentration of 6% (w/v), enzymatic hydrolysis under these optimum conditions generated 30 g/L of sugars or a recovery of 50% from dried sago hampas (Janggu and Bujang 2009).

Adeni et al. (2013) reported that recycling the hydrolysate in enzymatic hydrolysis of sago hampas for production of sugar greatly increased the yield from one cycle (27.8 g/L) to two cycles (73.0 g/L) and three cycles (138.5 g/L), a recovery of 70% from sago hampas (w/w). Fermentation of this sugar using baker's yeast generated 40.3 g/L of ethanol after 16 h or 93.3% theoretical yield based on glucose concentration.

22.8 Cellobiose from Sago Leaves

Apart from sago starch, a current study is looking at the possibility of producing cellobiose, a type of non-table sugar from sago leaves. Cellobiose can be obtained from enzymatic hydrolysis of cellulosic by-products, in this case sago leaves. The hard epidermis from fresh sago leaves is removed, and then the leaves chopped into 2 cm cubes, pulverized, and boiled for 30 min. The mixture is filtered and the tender solid hydrolyzed using a cellulase enzyme complex (containing cellobiohydrolases, endoglucanases, and β-glucosidases). Preliminary results showed the yield of cellobiose and glucose from fresh sago at 12 and 5%, respectively (Ahmad 2015). Cellobiose is a disaccharide, formed from 2 glucose molecules. Although it is not appropriate table sugar, and generally not consumed, it has several prebiotic properties especially in fermented dairy products, including bifidobacteria. Due to this, the market price for refined cellobiose (about USD 2000/kg) is much higher than glucose.

22.9 Conclusion

The main and only disadvantage of the sago crop is that the initial waiting period for harvest is 8–10 years, which could be one of the reasons for hectares of sago land being cleared for oil palm farming. The main benefit of producing cellobiose is that sago farmers would no longer have to wait so long to receive income from the first cycle of sago harvest, since pruned leaves and suckers have been shown to be potential raw materials to yield cellobiose. Sarawak exported 63,000 mt of food-grade sago starch in 2014, with a total value among the different starch types and prices at USD 29.3 million.

Locally, sago starch is sold at USD 500/mt ex-factory price. Converting this even into unrefined sugar can be profitable when compared to cane sugar at USD 800/mt. Bioconversion of sago starch into pure glucose would be much more lucrative since it fetches a higher price to sago starch at USD 12,600/mt. The overall cost for such enzymatic hydrolysis (excluding electricity and labor) has been approximated to be about USD 10/mt of starch, with a calculated profit of about USD 12000/mt.

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