

Review

Bioconversion of sago residue into value added products

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Bioconversion of the agro-residue offers the possibility of creating marketable value-added products. In this regard, sago residue which contains solid and liquid materials produced abundantly as a by-product from the sago starch processing industry. Due to its organic nature and low ash content, attempts have been made to produce several products such as fermentable sugar, enzyme, compost for mushroom, animal feed and adsorbent. Utilization of sago residue not only reduce the polluting effects from the sago processing industries, but will also provide an economic solution for waste management system at sago processing mills. This review focuses on the developments in processes and products for the value addition of sago residues through biotechnological means.

Key words: Sago palm, sago starch, sago residue, sago 'hampas', sago wastewater.

INTRODUCTION

In Sarawak, East Malaysia, agro-residues from sago starch processing industries are abundant and readily available. As stated by Bujang et al. (1996), it has been estimated approximately 7 tons (t) of sago pith waste was produced daily from a single sago starch processing mill. Currently, these residues were washed off into nearby streams together with wastewater and deposited in the factory's compound, which can lead to serious environmental problems. The problems of pollution from sago starch processing are more social and economic in nature than technological. It has been shown that sago wastewater represents high organic material ('hampas'), chemical oxygen demand (COD) and biological oxygen demand (BOD), which contravened the standard limit discharge enacted in the Environmental Quality Act, 1974 (sewage and industrial effluents regulation, 1979). According to starch processors, the installation of pollution control devices can be 20 - 50% of the total investment cost of a large-scale factory. Thus, through the exploitation

of these residues from sago starch processing industry, a promising materials resources such as sago bark (peelings from initial processing), sago 'hampas' (fibrous by products from crushing and sieving) and sago wastewater can be used for global environmental conservation and sustainable development. Sago 'hampas' which contained mostly starch and lignocellulosic materials is such a good choice to be used as a substrate for solid substrate fermentation either by fungal bioconversion or by enzyme or acid hydrolysis. Sago bark which contains mostly lignin is a rigid structure, traditionally used as a base around the sago processing mill. The present review addresses the progress that has been made in each of these resources with emphasis on the bioconversion into value added products.

SAGO PALM AND ITS PROCESSING INDUSTRY

The importance of starch production by sago palm is mainly focused in the Asia-Pacific region and South East Asia (Wang et al., 1996). Sago palms are those species of the genus *Metroxylon* belonging to the Palmae family. It is a species from which useful quantities of starch-rich flour can be extracted from stem tissue by shredding and

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sedimentation in water (Wina et al., 1986). The palm is by far the most important economic species and is now grown commercially in Malaysia, Indonesia, Philippines and New Guinea for the production of sago starch and/or conversion to animal food or fuel ethanol (Species Profiles for Pacific Island Agroforestry, http://www.botany.hawaii.edu/faculty/McClatchey/Publications/McClatcheyetal2004_Metroxylon.pdf). *Metroxylon* palms are used throughout the Indo-Pacific region by lowland-, marsh- and near-marsh-dwelling peoples. *Metroxylon* is of extreme importance to over a million people who use the palms as their primary dietary starch source. The largest sago growing areas and the world's biggest exporter of sago in Malaysia are to be found in the state of Sarawak, exporting about 44,700 t of sago starch in 2007 to Peninsular Malaysia, Hong Kong, Taiwan, Singapore and other countries (http://www.doa.sarawak.gov.my/statistik07_6_3_4.pdf). In contrast to other sources of starch, sago has an exceptionally high yield level. Under good conditions the yields vary from at least 15 t to possibly 25 t of dry starch/ha of *Metroxylon sagu* at the end of an 8-year growth cycle (Sago Palm: <http://www.ipgri.cgiar.org/publications/pdf/238.pdf>). *M. sagu* is considerably more productive for starch production compared with other *Metroxylon* species (Singhal et al., 2008). As claimed by Ishizaki (1997), sago is the highest starch (25 t) producer among all starch crops of the world; rice (6 t), corn (5.5 t), wheat (5 t) and potato (2.5 t).

Sago palm is an extremely hardy plant, thriving in swampy, acidic peat soils, submerged and saline soils where few other crops survive, growing more slowly in peat soil than in mineral soil (Flach and Schuilling, 1989; Hisajima, 1994). The palm is immune to floods, drought, fire and strong winds. As stated by Stanton (1993), research on sago palm should be explored as crop has several advantages which are: (1) economically acceptable; (2) relatively sustainable; (3) environmentally friendly; (4) uniquely versatile; (5) vigorous and (6) promotes socially stable agroforestry systems. In Sarawak, sago palms are grown commercially on small-holdings. A clump density of 590 palms/acre, or 1480 palms/ha, allows an annual harvest of 125 - 140 palms/year. Since 1982, the Sarawak government had developed a plantation crop and established a specialized research station (Flach, 1996). The world's first large-scale commercial plantation of 7700 ha near Mukah, was developed by the Sarawak land development agency. Sago reaches a maximum height of 25 m and a diameter of 40 cm, grows in clumps, has pinnate leaves and very thick stems. The stem of full-grown sago is about 20 m long and the fruits, in clusters, which take about 24 months to mature. Sago produces both pollinated (seeded) and parthenocarpic (non-pollinated) fruits. The leaflets are linear-ensiform, up to 1.5 m in length. The spadix is 3.5-4.5 m long, with the spathes quite spineless. The sago-palm derived products have many uses. In house construction, the leaves of sago are used for roof thatch and wall siding

and can be woven into bags, baskets, cages and rope and also utilized to make spoons and to wrap food (Singapore Zoological Gardens Docents, <http://www.szgdocent.org/ff/f-sago.htm>). The decaying trunks of the sago palm are a source of sago palm beetle grubs (*Rhynchophorus ferrugineus/bilineatus*), an excellent source of protein (Species Profiles for Pacific Island Agroforestry, http://www.botany.hawaii.edu/faculty/McClatchey/Publications/McClatcheyetal2004_Metroxylon.pdf). The rachis of fronds is used for walls, fastened between horizontal posts with lathes on them. The bark (outer cortex) of sago palm is used as flooring and as planking for crossing short streams or swampy areas and used for firing in factory. Various parts of the plant are used for traditional medicines, toys and other miscellaneous items. Ground pith sometimes is used as an animal feed, especially for pigs. When dried, it is also used for horses and for chicken. The rice-straw mushroom (*Volvaria volvacea*) can also be cultivated on refuse from starch extraction (Flach, 1996).

The pith consists mainly of starch, which has to be separated from the cellulosic materials will undergo several stages of process in a way to extract good quality and quantity of sago starch (Bujang and Ahmad, 2000). The soft tissue of the pith is obtained from a rather laborious task of removing the hard bark about 2 - 3 cm thick upon felling of the massive trunk. The farmer grated the pith using plank studded with numerous nails which shred the pith into fine granules for starch extraction. In Sarawak, fully mechanical processes are used for starch isolation by modern factories. The isolation of sago starch involves debarking, rasping, sieving, settling washing and drying. The chips obtained are further disintegrated using a hammer mill. The resulting starch slurry is then passed through a series of centrifugal sieves to separate the coarse fiber. Further purification is carried out by separation in a nozzle separator to obtain pure starches. Dewatering of the starch is achieved using a rotary drum dryer, followed by hot air drying. During the processing of sago starch three major types of by-products was generated, they are bark of sago trunk, fibrous pith residue (commonly known as 'hampas') and wastewater (Figure 1). Bark and 'hampas' are classified as a solid residue whereas wastewater is liquid residue. Instead of starch, small amount of non-starch polysaccharide (NSP), known as cellulose, hemicelluloses and lignin are found in sago pith. According to Sun et al. (1999), the cellulose fraction consisted of 89% glucose and small amounts of other sugars, such as xylose, rhamnose, arabinose, mannose, fucose and galactose, whereas xylose and glucose were found to be the major components of the isolated hemicelluloses, together with noticeable amounts of arabinose and galactose and small amounts of rhamnose, mannose, fucose and uronic acids. Lignins, on the other hand influence the woody structural rigidity by stiffening and holding the fibers together. Furthermore, the presence of silica, tannins and other phenolic substances make the

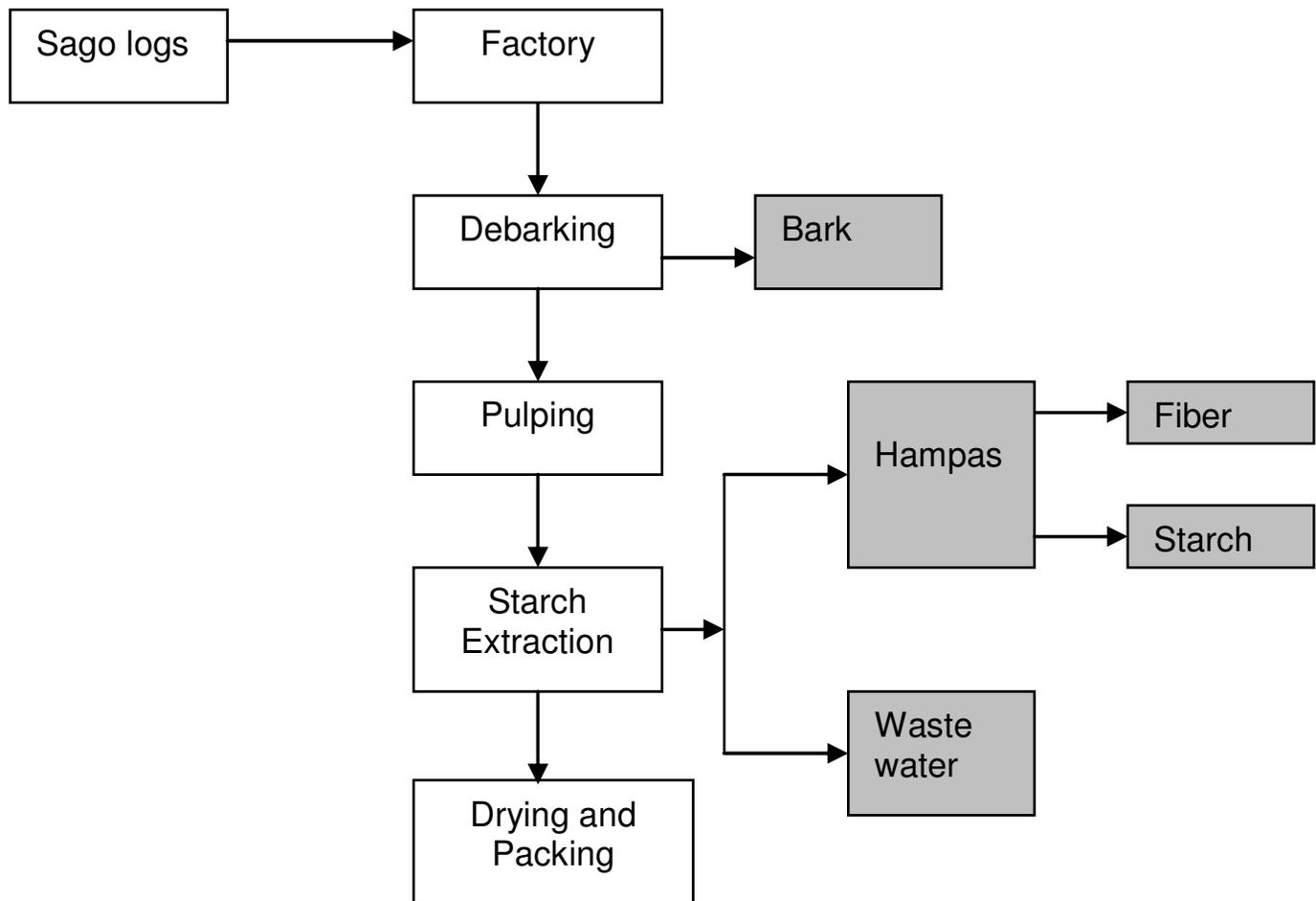


Figure 1. Schematic flow diagram for sago processing (Yean and Lan, 1993).

chemical studies of sago pith will be very difficult.

SAGO SOLID RESIDUE

A residue is a substance resulting from the processing of a product. It becomes a co-product or a by-product when profitable use is made of it. If not, the residue becomes a waste, which is defined as a material with no apparent market, social, or environmental value, that constitutes an environmental nuisance and a source of pollution. In starch processing, fibrous by-products which contained starch residue is the main problem especially for the bigger factories, which produce massive quantities. Dealing with this waste is difficult, as it is not easily dried, due to its high moisture and starch contents (Sriroth et al., 1999). Numerous studies on solid residues for developing industrial products have been carried out in the world; however it was limited by the nature and composition of lignocellulosic biomass (Sanchez and Cardona, 2008). Sago solid residue, bark and 'hampas' are largely composed of celluloses and lignin, therefore,

both a waste and a pollutant (Vikineswary et al., 1994).

Sago bark

Sago bark is one of the solid residues in the sago production industries. The bark accounts for about 17% of the logs processed, with the estimate production of 5-15 tons bark per day (Chew and Shim, 1993). Lignin is the main component of the sago bark and it is strongly associated with the hemicelluloses in the cell walls of sago pith. According to Sun et al. (1999), this lignin contains a high proportion of non-condensed syringyl units, together with small amounts of non-condensed guaiacyl units and fewer non-condensed p-hydroxyphenyl units. Usually, the bark is used as a platform around the factory and as footpaths of houses, instead of burned. The locals use the bark of the trunk as timber fuel, wall materials, ceilings and fences (Schuiling and Jong, 1996). At present, sago bark is processed through bio-composite method to produce sago plywood, wall tiles and particleboards which have potential as building

materials (Rahman K, University Malaysia Sarawak, Malaysia, personal communication).

Sago 'hampas'

Sago 'hampas' is a starchy lignocellulosic by-product generated from pith of *Metroxylon sago* (sago palm) after starch extraction. The amount of 'hampas' released from the sago processing factory depends mostly on the quality of the extraction process. In Sarawak, especially in Sibu and Mukah Division, about 50-110 t of sago 'hampas' are produced daily. 'Hampas' contains approximately 66% starch and 14% fibre on a dry weight basis of which about 25% is made up of lignin (Chew and Shim, 1993). With the significant amount of starch left behind within the hampas, it has been used as a feedstuff for swine in sago processing areas. The feeding value of sago pith and pith residue is close to that of sweet potato residues and as such they can be utilized more effectively by ruminants (Horigome et al., 1991). The 'hampas' may be used as animal feed, compost for mushroom culture, for hydrolysis to confectioners' syrup and for particleboard manufacture (Phang et al., 2000).

As noted by Kumaran et al. (1997), the utilization of sago 'hampas' as a cheap substrate has it great potential for laccase production through solid substrate fermentation (SSF). In addition, the economics of SSF of sago 'hampas' using *Pleurotus sajor-caju* offers an extra income generation for sago growers. The fungus grown on the 'hampas' with a C: N ratio of 35:1 exhibited high laccase activity together with variable cellulose and xylanase activities. *Pycnoporus sanguineus* also showed good growth during solid state fermentation of sago hampas, which was supplemented with urea as nitrogen urea, again producing high amount of laccase (Rifat et al., 2003).

The sago 'hampas' largely composed of cellulose and lignins have some potential as a biosorbent (Vickineswary et al., 1994). They may be produced by grinding sago 'hampas' using food processor, drying in an oven at 105°C for 24 h and then screening through sieves to give adsorbents with a known particle size range, which can be used to adsorb lead and copper ions from solutions (Quek et al., 1998). This finding claims sago 'hampas' is a better adsorbent for lead than for copper, having higher initial sorption rate and greater sorption capacity. As found by Kadirvelu et al. (2004), the activated carbon prepared from sago waste is reported to be effective and economically attractive adsorbent for Hg(II), with adsorption equilibrium of 105 min for 20 mg/l and 120 min for 30, 40 and 50 mg/l of Hg(II) concentrations.

The 'hampas' which is in the form of dried-powder has shown its possibility to be converted into fermentable sugar through acid and enzymatic hydrolysis. As mentioned by Kumoro et al. (2008), an amount of 0.6234

glucose per 'hampas' (g g^{-1}) was found when hydrolyzed with 1.5 M sulphuric acid, at 90°C after 120 min, whereas through hydrolysis by glucoamylase, it was 0.5646 glucose per 'hampas' (g g^{-1}) was yielded utilizing 6 AGU per ml enzyme after 30 min reaction time. The use of higher acid concentration and higher temperature are more effective to enhance the sugar yield rather than extend the hydrolysis reaction time, as higher temperature provides greater energy to break down the linkage of fibrous sago 'hampas'. The production of 46 g/l fermentable sugars was obtained after 96 h incubation under optimum condition by *Trichoderma* sp. KUPM0001 during solid substrate fermentation of sago starch processing waste 'hampas' (Shahrim et al., 2008). Under this optimized condition, maximum enzymes activity also being observed.

The study by Apun et al. (2000) indicates that the indigenous isolate identified as *Bacillus amyloliquefaciens* UMAS 1002 has the ability to hydrolyze sago 'hampas' into reducing sugars. From the studies amyolytic and cellulolytic enzymes also being produced by the bacteria, thus create an extra advantage in the degradation of sago 'hampas'. Moreover, the need of adding another organism or enzyme for hydrolysis can be avoided. Through the cooperative of cellulolytic and amyolytic enzymes, the hydrolysis processes of the sago 'hampas' will be more effective since cellulose and starch are the main component of the 'hampas'. Studies on production of carboxymethyl cellulose (CMC) from sago 'hampas' by esterification using sodium monochloroacetate and sodium hydroxide has reveals that under optimized conditions the product has a large degree of substitution (DS) of 0.821 (Pushpamalar et al., 2006).

SAGO LIQUID RESIDUE

The process of starch extraction from sago pith requires large quantities of water, thus huge amount of wastewater was released from sago mills. The bulk of the sago wastewater is liquid (94-97%), whereas the solid waste called 'hampas' will render numerous problems in the treatment. In addition, the lack of visible enforcement from the relevant authorities on effluent disposal, resulted in serious contamination of the rivers. Based on study by Phang et al. (2000), the waste water is usually discharged into the rivers, each factory producing about 10-22 tons waste water per day which contains a very high carbon to nitrogen ratio (105:0.12), but it has been made more suitable for fermentation by anaerobic fermentation in an up-flow packed bed digester. The digested effluent with an average C: N: P ratio of 24:0.14:1 supports growth of *Spirulina platensis* (*Arthrospira*). The highest crude protein, carbohydrate and lipid content of the biomass were 68, 23 and 11%, respectively. The reduction in COD, ammoniacal-nitrogen and phosphate levels of the digested effluent reached levels of 98.0, 99.9 and

99.4%, respectively.

There are newer possibilities for the design of low-cost and compact, on-site waste treatment systems with very short retention periods. A hybrid reactor which combines the advantages of both fixed-film and up-flow anaerobic sludge blanket systems for the treatment of sago waste water for reduction of COD was operated at organic loading rates varying from 10.4 to 24.6 kg COD/m³d (Banu et al., 2006). After 120 days of start-up, the COD was decreased and efficient removal of solid was observed. The COD removal varied from 91 to 83%, while the removal total solids was in the range of 56 - 63% and that of volatile solids varied from 67 - 72%. Another important application lies in its use as an additional carbon in anaerobic digesters for the production of biogas (Abd-Aziz, 2002).

Studies by Vickineswary et al. (1997) have shown that *Rhodopseudomonas palustris* strain B1, the indigenous phototrophic isolate, had the ability to grow in 50% sago effluent and produce biomass which had potential as an aquaculture. A high biomass concentration of 2.5 g/l with a pigment content of about 1.1 mg carotenoid per g cell mass was achieved after 96 h of growth in anaerobic-light culture system together with a reduction of the COD of the sago effluent. This was considered to be of value since carotenoids are nutraceuticals having a huge market worldwide. Other findings have shown that the biomass is non-toxic to *Artemia* and can be suitable supplement for prawn feed (Getha, 1995).

CONCLUSION

The possibility to use sago starch in the production of food, polymer, pharmaceutical and textile industry will lead to the high demand of sago starch in the market and concomitantly will increase the generation of sago residues and therefore will produce more pollution to the environment. It can be concluded that bioconversion of sago 'hampas', the solid residue could be economically useful for the production of fermentable sugar, enzymes, feed, compost, etc. In this regard, production of bioethanol could be an area to be exploited, as it is gaining much importance in recent years. On the other hand, it will help solve environmental problems and reduce dependence on petroleum resources. However, efforts should be also made for improving sago 'hampas' hydrolysis conditions as it acts as an important source for bioethanol production. Thus effective conversion of sago 'hampas' into fermentable sugars is a vital task that needs further inputs in terms of research and development.

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