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Efficiency of Starch Extraction from the Pith of Sago Palm: A Case Study of the Traditional Method in Tebing Tinggi Island, Riau, Indonesia

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Abstract On Tebing Tinggi Island, Riau, Indonesia, sago starch is no longer commonly used as a staple food; it is more common as an ingredient in cake-making. Following the traditional method of extracting the starch, the pith of two debarked logs, each ca.1 m long, was grated with a large grater. The pith was then spread on a platform covered with a nylon mesh sieve near a small river or pond and extracted by trampling it with watering. This study was conducted to clarify the starch extraction efficiency of the traditional method compared to chemical extraction. The percentage of starch extracted from the pith averaged 70.5%, which indicates that the logs were harvested at a suitable stage. The amount of starch extracted from the two logs using the traditional method averaged 32.3 kg, which was 48.0% of the chemically analyzed yield of 67.1 kg. The percentage of starch in the extracted residue was 55.7% on a dry weight basis, while the starch content of the extracted residue from the two logs averaged 35.1 kg or 52.1% of the chemically determined starch yield. Scanning electron microscope observations showed that no starch granules were present outside of the parenchyma cells of the pith after extraction, but numerous starch granules remained inside the parenchyma cells because the cell walls were still intact. On Tebing Tinggi Island, the efficiency of starch extraction from sago palm using the traditional method was about 50%. The low efficiency was attributed to incomplete grating of the pitch.

Key words: extraction efficiency, Indonesia, Riau, sago palm, starch, traditional method

サゴヤシ髄部からのデンプン抽出効率 ― インドネシア・リアウ州トゥビンティンギ島での伝統的方法での一事例 ―

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要旨　インドネシア，リアウ州トゥビンティンギ島では，今日，サゴヤシデンプンは，一般的には主食用ではなく，菓子製造用に利用されている．当島でのサゴデンプンの伝統的抽出方法では，約1mの長さに切断したサゴヤシ樹幹（ログ）2本を1組として剥皮後，髄部を大型のオロシガネで粉砕する．そして，小川や池の近くに設営されたプラットフォームにナイロンメッシュを篩いとして広げ，その上に粉砕髄を載せて，水をかけながら足で踏み出しながら抽出する．本調査では，この島におけるサゴヤシデンプンの伝統的抽出方法による抽出効率について，化学的に分析した結果との比較において

検討した．供試した各ログ髄部のデンプン含有率は平均値で70.5%で，収穫適期樹と判断された．伝統的方法によるデンプン収量は，ログ2本当たり平均値で32.3kgであり，この値は化学的に分析したデンプン収量の平均値67.1kgの48.0%であった．抽出残渣の乾物重当たりのデンプン含有率は，平均55.7%で，抽出残渣中のデンプン含有量は，ログ2本当たり平均値で35.1kgであった．この値は，化学分析によるデンプン収量の52.1%に相当した．抽出終了後の粉砕髄を走査型電子顕微鏡で観察した結果，柔細胞の外側にはデンプン粒は残存していなかった．しかし，細胞壁が破断されていない髄部柔細胞が多数観察され，その内部には多数のデンプン粒が存在した．以上より，インドネシア，リアウ州トゥビンティンギ島における伝統的方法によるサゴヤシデンプンの抽出効率は約50%であり，抽出効率がこのように低い原因として，サゴヤシ髄部の粉砕方法に問題があることが示唆された．
キーワード：インドネシア，サゴヤシ，抽出効率，伝統的方法，デンプン，リアウ州

Introduction

The starch yield of sago palm (*Metroxylon sagu* Rottb.) is mainly determined by the amount of accumulated starch in the trunk, but the extraction efficiency is also an important factor determining the yield. The extraction efficiency is affected by various factors, including the method of grating or pounding the pith, the manner of extracting the starch from the grated or pounded pith, and the frequency of extraction. The starch extraction efficiency needs to be improved when modern as well as traditional methods of extraction are used (Ono 1994).

Various types of graters and choppers are used to grate and pound the pith, respectively, in the traditional extraction method (Yamamoto 1998). In addition, there are two methods of extracting the starch from the grated or pounded pith, i.e. kneading and trampling with watering. Both methods are used on Sulawesi Island. Hand kneading is used in the eastern district, and the trampling technique by foot is used in the western district. (Nishimura and Laufa 2002). With both techniques, the process continues until the extracted water runs clear. Few studies are available on the extraction efficiency of traditional methods; only Shimoda and Power (1986) and Ohmi et al. (2004) have reported cases from the Sepik River basin in Papua New Guinea and Layte Island in the Philippines, respectively.

This research was conducted to clarify the starch extraction efficiency of the traditional method in Tebing Tinggi Island, Riau, Indonesia. About 60,000 ton of sago starch was produced on this island in 1998 (Jong 2001), and the starch was used primarily for cake-making.

Materials and Methods

This research was performed in a sago farmer's garden in Tebing Tiggi Island, Riau, Indonesia. Harvested trunks were cut by the owner into ca. 1 m-long sections (log), and six logs (logs A–F) were randomly selected. The logs were debarked with an axe, and the weight of the bark and pith of each log were recorded. About 100 g samples of the bark and pith were taken from each log, and their fresh weight was measured on a portable electronic balance (HL-200 type, Kagakukyoei Co., Ltd.). The samples were then dried in an oven at 80 ℃ for 2 days, and the dry weights were recorded. Following the traditional method, the debarked logs (pith) were randomly grouped into sets of two logs (logs A and B, logs C and D, and logs E and F; Table 1) and grated with a large grater (Fig. 1). The grated pith was spread on a platform covered with a nylon mesh sieve, and the starch was extracted by trampling it with watering until the water ran clear (Fig. 2). The raw and dry starch weights were measured after dehydration of excess water and oven-drying at 80 ℃ for 2 days, respectively. After the starch was extracted from each group of two logs, about 100 g of extracted residue was taken with three replications and oven-dried, as reported above.

Table 1. Some characters of harvested logs.

Log	Log							Bark			Pith		
	lengh (cm)	diameter (cm)	volume (m^3)	FW[1)] (kg)	DM[2)] (%)	DW[3)] (kg)	density[4)] (kg/m^3)	FW (kg)	DM (%)	DW (kg)	FW (kg)	DM (%)	DW (kg)
A	100	50.9	0.203	151.5	42.6	64.5	746.3	34.5	34.1	11.8	117.0	45.1	52.8
B	100	50.3	0.199	163.5	44.6	72.9	821.6	40.3	32.9	13.3	123.2	48.4	59.6
C	112	44.6	0.175	137.8	42.7	58.8	787.4	48.9	33.8	16.5	89.0	47.6	42.4
D	96	46.8	0.165	133.0	44.7	59.5	806.1	32.8	37.1	12.2	100.2	47.2	47.3
E	110	44.0	0.167	147.5	45.4	67.0	883.2	38.6	35.0	13.5	108.9	49.1	53.5
F	98	37.1	0.106	87.0	43.8	38.1	820.8	26.0	30.2	7.9	61.1	49.6	30.3
Average	103	45.6	0.169	136.7	44.0	60.1	810.9	36.8	33.9	12.5	99.9	47.8	47.7
SD[5)]	6.7	5.0	0.035	26.6	1.1	12.0	45.1	7.7	2.3	2.8	22.6	1.6	10.3

[1)] Fresh weight. [2)] Dry matter. [3)] Dry weight. [4)] Log fresh weight / volume. [5)] Standard deviation.

Fig. 1. Using a large grater to grate the pith.

Fig. 2. Starch is extracted from the grated pith by trampling it with watering on a platform covered with a nylon mesh sieve.

Oven-dried samples of the pith before grating and the extracted residue were ground using a vibration mill (Vibrating Sample Mill T1-100, CMT Co. Ltd.). After sugars were extracted from the ground sample (0.2g) using 80% hot ethanol, starch was extracted using $HClO_4$ (4.6*N*) following the methods of Murayama et al. (1955). The analysis of starch as glucose was performed using the Somogyi method (1945), and the percentage of starch was calculated by multiplying 0.9 times the percentage of glucose. For scanning electron microscopic studies, pith samples before and after grating at various stages during starch extraction were fixed and stored in 80% ethanol before shipment to Japan. The stored samples were soaked in 40% ethanol and then in water. Thereafter, the material was frozen rapidly with slush nitrogen (–210 ℃) followed by vacuum freeze-drying (–60 ℃, 10^{-3} Pa) (Zakaria et al. 2000). Surface or cross sections taken with a razor blade were coated with OsO_4 or platinum so that the dissected surfaces were exposed. Specimens were observed with a scanning electron microscope (SEM) (JSM6301F, JEOL Co., Japan).

Table 2. Fresh weight, dry matter percentage and dry weight of bark and pith of the logs.

Log	Bark					Pith				
	FW (kg)		DM (%)	DW (kg)		FW (kg)		DM (%)	DW (kg)	
A	34.5	(22.8)[1)]	34.1	11.8	(18.3)	117.0	(77.2)	45.1	52.8	(81.7)
B	40.3	(24.6)	32.9	13.3	(18.2)	123.2	(75.4)	48.4	59.6	(81.8)
C	48.9	(35.5)	33.8	16.5	(28.1)	89.0	(64.5)	47.6	42.4	(71.9)
D	32.8	(24.7)	37.1	12.2	(20.5)	100.2	(75.3)	47.2	47.3	(79.5)
E	38.6	(26.2)	35.0	13.5	(20.1)	108.9	(73.8)	49.1	53.5	(79.9)
F	26.0	(29.9)	30.2	7.9	(20.7)	61.1	(70.1)	49.6	30.3	(79.3)
Average	36.8	(26.9)	33.9	12.5	(20.8)	99.9	(73.1)	47.8	47.7	(79.2)
SD[2)]	7.7	(4.8)	2.3	2.8	(3.7)	22.6	(4.7)	1.6	10.3	(3.7)

[1)] Numerals in the parenthesis indicate the relative values to log weight (Table 1). [2)] Standard deviation.

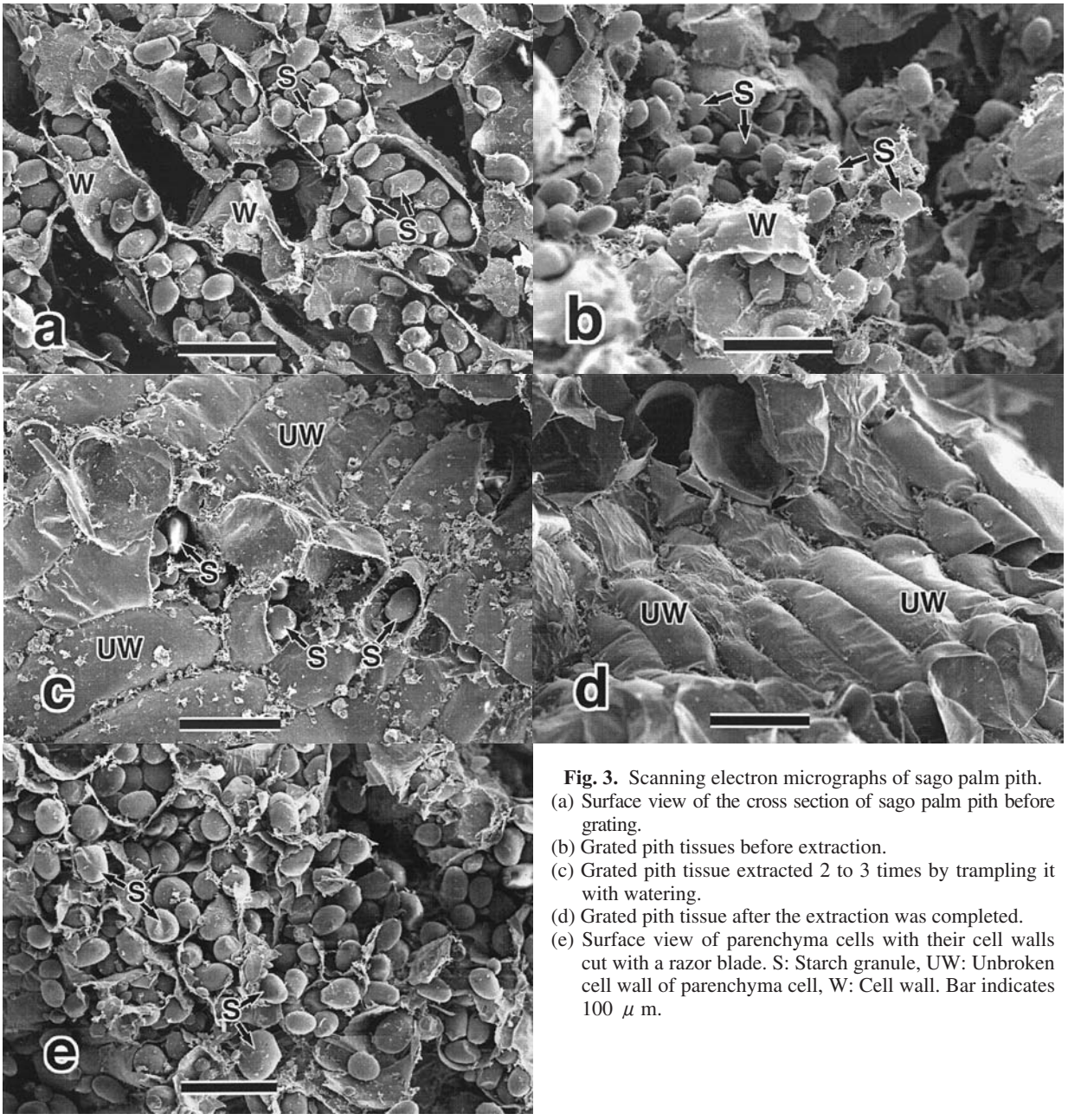

Fig. 3. Scanning electron micrographs of sago palm pith.
(a) Surface view of the cross section of sago palm pith before grating.
(b) Grated pith tissues before extraction.
(c) Grated pith tissue extracted 2 to 3 times by trampling it with watering.
(d) Grated pith tissue after the extraction was completed.
(e) Surface view of parenchyma cells with their cell walls cut with a razor blade. S: Starch granule, UW: Unbroken cell wall of parenchyma cell, W: Cell wall. Bar indicates 100 μ m.

Results

The average log length, diameter, volume, and fresh weight were 103 cm, 45.6 cm, 0.169 m^3, and 136.7 kg, respectively (Table 1). The average dry weight and percentage of dry matter of the logs were 60.1 kg and 44%, respectively. The fresh and dry weights of log F were lower than those of the other logs. The density (fresh weight/volume ratio) in logs E and A had the highest (883.2 kg/m^3) and lowest values (746.3 kg/m^3), respectively, and the average value was 810.9 kg/m^3.

The fresh and dry weights of bark and pith and their percentage of dry matter are shown in Table 2. The average fresh weight of pith per log and the percentage of dry matter were 99.9 kg and 47.8%, respectively; these values were higher than those of bark, 36.8 kg and 33.9%, respectively. The average dry weights of bark and pith were 12.5 kg and 47.8 kg/log, respectively. The percentages of the fresh and dry weights of bark in a log ranged from 22.8 to 35.5% (average: 26.9%) and 18.2 to 28.1% (average: 20.8%), respectively, while those of pith ranged from 64.5 to 77.2% (average: 73.1%) and 71.9 to 81.8% (average: 79.2%), respectively.

Scanning electron microscopic observations revealed that a large number of starch granules were stored in the parenchyma cells of the pith (Fig. 3a).

Immediately after grating, numerous starch granules were observed in the broken cell walls and inside the parenchyma cells of the pith (Fig. 3b). The grated pith whose starch had been extracted two or three times by trampling it with watering, a considerable number of starch granules remained inside the parenchyma cells (Fig. 3c), but no starch granules were observed outside the parenchyma cells once the extraction was completed (Fig. 3d). However, a large number of parenchyma cells had their cell walls intact, even after grating. Therefore, the presence of many starch granules was observed when the cell walls were cut with a razor blade (Fig. 3e).

The average percentage of starch in the pith of the logs, as determined by chemical analysis, was 70.5%, although the percentage in log A (53.7%) was lower than those of the other logs: 72.1–78.7% (Table 3). The starch yield of each log ranged from 21.9 to 43.9 kg, with an average value of 33.5 kg. The starch yield using the traditional method ranged from 27.5 to 38.8 kg (average: 32.3 kg) for two combined logs and was equivalent to 43.0 to 53.7% (average: 48.0%) of the starch yield chemically determined.

The extracted residue of grated pith contained 49.9 to 61.7% (average: 55.7%) of starch on a dry weight basis (Table 4). The dry weight of the extracted residue of the two combined logs was determined by the difference between the pith dry weight and the dry starch yield by the traditional method. And the starch content remaining in the extracted residue was estimated by multiplying the dry weight of the extracted residue and the percentage of starch in the extracted residue. The estimated starch content in the extracted residue ranged from 28.1 to 40.8 kg (average: 35.1 kg), and these values were equivalent to 43.9 to 56.4% (average: 52.1%) of the chemically determined starch yield.

Table 3. Comparison of starch yields by chemical analysis and traditional extraction method.

Log	Pith dry weight (kg)	Chemical analysis method: Starch[1] (%)	Chemical analysis method: Starch yield[2] (kg)	Chemical analysis method: Starch yield[2] (kg) (a)	Traditional method: Starch yield[2] (kg) (b)	Extraction efficiency (%) (b) / (a)×100
A	52.8	53.7	28.4	72.3	38.8	53.7
B	59.6	73.6	43.9			
C	42.4	72.3	30.7	64.9	30.7	47.3
D	47.3	72.3	34.2			
E	53.5	78.7	42.1	64.0	27.5	43.0
F	30.3	72.1	21.9			
Average	47.7	70.5	33.5	67.1	32.3	48.0
SD[3]	10.3	8.6	8.4	4.6	5.8	5.4

[1] Dry weight basis. [2] Dry starch. [3] Standard deviation.

Discussion

The percentage of starch in the pith of the log averaged >70%, except for a lower percentage in log A (53.7%). Log A may have been located at the top part of the trunk, where starch tends to accumulate last (Jong 1995; Yamamoto et al. 2003). The results show that almost all of the trunks that were cut into logs had been harvested at a suitable growth stage. The slender diameter of log F revealed that this trunk grew in

Table 4. Starch content in the extracted residue by traditional method.

Log	Pith dry weight (kg) (a)	Traditional method: Starch yield[1] (kg) (b)	Traditional method: Dry weight of ER[2] (kg) (c)	Chemical analysis: Starch yield[1] (kg) (d)	Chemical analysis: Starch content[1] in ER[2] (%) (e)	Chemical analysis: Starch content[1] in ER[2] (kg) (f)	Percentage of starch content in ER (%) (g)
A B	112.4	38.8	73.6	72.3	55.5	40.8	56.4
C D	89.6	30.7	58.9	64.9	61.7	36.3	55.9
E F	83.8	27.5	56.3	64.0	49.9	28.1	43.9
Average	95.3	32.3	62.9	67.1	55.7	35.1	52.1
SD[3]	15.1	5.8	9.3	4.6	5.9	6.4	7.1

[1] Dry starch. [2] Extracted residue. [3] Standard deviation. [4] Formula for gaining the values; Weight of ER (c) = (a) - (b), Starch content in ER (f) = (c)×(e) / 100, percentage of starch content in ER (%) (g) = (f) / (d)×100.

shadier conditions than the others (Yamamoto 1998).

The starch extraction efficiencies of the traditional method ranged from 43.8 to 53.7%, with an average of 48.0%. Although few reports are available on starch extraction efficiency by traditional extraction methods, Shimoda and Power (1986) reported efficiencies of 56.9 to 71.8% from the Sepik River basin in Papua New Guinea. The efficiencies in this research were similar to or slightly lower than the values reported by these authors. On the other hand, Ohmi et al. (2003) reported an efficiency of 39.3% from Layte, Philippines, which was somewhat lower than the value obtained in this research. All these results show that a considerable amount of starch was not extracted from the smashed pith and remained in the residue after extraction. The variations in starch extraction efficiencies may be due to different methods of smashing the pith and/or starch extraction from the smashed pith.

Traditionally, various types of graters, and various types of choppers, made of wood or stone and with or without metal edges, have been utilized as tools to grate and pound sago palm pith, respectively. The differences in the thinness of the grated and pounded pith and in the extraction efficiencies of the various tools used to grate and pound it need to be precisely described. Ohmi et al. (2003) reported a lower starch extraction efficiency from grated pith that was smashed by hand in the traditional method than from that smashed by motor-driven graters. Two methods are used to extract starch from the smashed pith, i.e., kneading and trampling it with watering. According to a report by Nishimura and Laufa (2002), the two methods are used on Sulawesi Island, Indonesia, However, the manual method is used in the eastern district of the island, while the trampling method is used in the western district. The trampling method is used on Tebing Tinggi Island, Riau, Indonesia, where this research was conducted. The differences in the starch extraction efficiency of the two methods need to be clarified.

To determine why the traditional method is less efficient than the chemical extraction, a scanning electron microscope was used with pith samples before and after grating at various stages during the starch extraction process. A large number of starch granules were stored in the parenchyma cells of the pith. Many starch granules were observed in the broken cell walls and inside parenchyma cells of the pith immediately after grating. The number of starch granules decreased during the extraction process until, finally, no starch granules were found on the surface of the parenchyma cells of the grated pith. This coincides with the result of Ohmi et al. (2003), who reported that the percentage of starch in the extracted residue decreased with increasing extraction frequency. On the other hand, microscopic observations also revealed that a considerable number of parenchyma cell walls were intact, even after grating, and that many starch granules were present when the cell walls were cut with a razor blade. The results suggest that the lower starch extraction efficiency of the traditional method might be caused by the incomplete destruction of parenchyma cell walls of the pith. Suda (1995) reported that beating the pounded pith with a bamboo rod to increase the efficiency of starch extraction was common practice in a Kubo-speaking village on the Strickland River in the Western Province of Papua New Guinea.

Improving the efficiency of starch extraction from sago palm is important, not only for small-scale processing by traditional methods but also for modern large-scale sago factories (Ono 1994). Ono (1994) reported that smashing the sago pith using raspers and hammers mills resulted in a finer texture of the smashed pith and, concomitantly, greater efficiency; however, there was more fiber contamination.

Increased efficiency in starch extraction from sago palm is a fundamental and important development to improve the starch yields. Further research with regard to extraction techniques and their efficiencies is necessary.

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