Effect of Hopper Angle and Teeth Density on Performance of Cylinder Type Sago Rasping Machine

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Abstract. Rasping is the most frequently useful method to disintegrate or to break down the cellular structure of sago pith for mechanical processing. The objective of this study was to investigate the effect of hopper angle and teeth density on rasping performance of cylinder type sago rasping machine. In the experiment, three levels of hopper angle i.e. 0° (H1), 22.5° (H2) and 45° (H3) and three levels of teeth density i.e. 2.2 cm × 4 cm (D1), 2.2 cm × 3 cm (D2), and 2.2 cm × 2 cm (D3) were examined. The rasping performance test was carried out by measuring rasping capacity, starch percentage, and starch yield. The experimental results showed that the combination of hopper angle and teeth density significantly affected rasping capacity and starch yield, but did not affect the starch percentage. The highest rasping capacity (1891 kg/hour) and the highest starch yield (790 kg) were resulted under experimental condition of teeth density 2.2 cm x 3 cm with hopper angle of 22.5 degree. In conclusion, the optimum condition to achieve highest rasping performance was teeth density 2.2 cm x 3 cm with hopper angle 22.5°.

1. Introduction
Sago starch processing is purposed to extract the starch from sago trunk. It can be classified into three categories namely traditional processing, mechanical processing and combination of the two. Traditional method of sago starch processing was a time and labor intensive process. In addition, the starch has been produced was low quality grade. In contrast, mechanical processing has relatively shorter processing time and more hygienic process and producing high quality starch. However, the principles and methods of sago starch processing are similar for both traditional and mechanical one, differing only in the scale of operation and the equipments have been used.

Papua and West Papua Province have the largest potentials of sago palm (Metroxylon spp.) in Indonesia, even in the world. Approximately 1.471,232 hectares, mostly natural sago forest were existed in these areas [1]. Flach [2] estimate a total of 1,200,000 ha wild stands or natural sago forest and 14,000 ha stands of semi cultivated sago palm was located in West Papua. By using the area of 1,471,232 ha, Matanubun and Maturbong [1] predict the sago starch production potential in West Papua is about 12,035,555 tons/year. According to Bintoro [3], the potential yield of natural sago forest is around 20-40 tons starch/ha/year. It means that the total potential yield of sago in this region is around 29,424,640-58,849,280 tons/year. The most recently research conducted by Jong and Ho [4] concluded that in the natural sago forest in South Sorong, West Papua, dry starch yield potential was
between 10-15 tons/ha/year. Therefore, the total dry starch yield potential was between 14,712,320-22,068,480 tons/year.

Despite Papua and West Papua Province have the largest potential of sago palm in the world, unfortunately, the sago starch production and utilization is very small comparing with its potential. Millions of tons of the starch is not harvested and disappear every year. Matanubun and Maturbong [1] stated that utilization of sago resources in West Papua is less than 5% of its existing potential. Up to the present time, farmers in this region cut sago trees and process mainly for subsistence use and sell locally but they exploit only a very small amount compared with its potential. Consequently, a large number of mature sago palm are not harvested and lost every year. Recently, there has been no significant increase in sago starch production in West Papua. In contrast, the sago industry in Malaysia, in the State of Sarawak is well established and has become one of the important industries contributing to export revenue [5], [6].

Up to the present time, in most part of Papua and Papua New Guinea, starch was extracted using traditional method. This method was ineffective and inefficient, consequently, the starch production was very low both in term of quantity and quality. Millions of tons of the starch was not harvested and lost every year. In order to increase sago starch production in those areas, farmers should apply mechanical method of starch processing. Applications of mechanical equipment in the form of appropriate technology are suitable for most developing countries. Imported high-technology mechanical equipment not only has a high price but also need a high skill to operate them. In doing so, it is necessary to provide mechanical equipment which is suitable and easy to use by ordinary farmers.

Rasping sago pith is aimed to disintegrate or to break down the cellular structure of the pith. The are others term that commonly used synonymous with pith disintegration such as pith macerating [7] and pith pulverizing [8], [9]. Meanwhile, rasping is synonymous with grating. By doing so, the starch granules which exist in the cells is freed or loosen, thus it is able to suspend into water during extraction process. The amount of starch obtained depends on how fine the level rasping and the efficiency of starch washed out from the rasped pulp. The more finely the pith is rasped, the more starch can be extracted in the subsequent rinsing process. Numerous factors affect the effectiveness and efficiency of a sago rasping machine, some of which are related to the mechanical properties of the material, while the others depend on geometry and adjustment of the teeth edge and on the kinematic conditions. In previous researches, a prototype of cylinder type sago rasping machine was developed even had been widely used by sago farmer in West Papua Province. Functionally, it worked properly but it still has some drawbacks, therefore it needs to be improved further in order to achieve a higher level of performance. The objective of this research is to investigate the effect of hopper angle and teeth density on rasping performance.

2. Materials and methods

Although there are many ways to break down the cellular structure of sago palm pith, in practice almost all small-scale processing of sago uses rasping machine or raspers. A new variant of cylinder type sago rasper was developed in this study (figure 1).

2.1. Overall Structure of the Sago Rasper Machine

This sago rasping machine consisted of several main components. They are (a) a rotating cylinder covered with sharp teeth on its circumference surface enclosed in a housing made of 0.2 cm thick stainless steel plate. The cylinder was made of steel pipe is 16.8 cm in diameter and 22 cm in length. The tooth is 0.4 cm in diameter and 2 cm in height and made of stainless steel rod. There are three cylinders with different teeth density tested in this study (Figure 2); (b) a 4-stroke gasoline engine (6.5 hp or equal to 4.85 kW) was used as power source; (c) Power from engine is transmitted to the cylinder using of pulleys and V-belt; (d) Main frame is made of 0.5 cm thick equal angle (L-shape) 5 cm × 5 cm × 0.5 cm steel bar. In addition, it is equipped with cylinder’s cover and feeding plate.
(hopper) both made of stainless steel plate with 2 mm in thickness. It is also equipped with an output component to facilitate the rasped sago pith (repos) throughput from cylinder into collecting bag.

Figure 1. Overall structure of cylinder type sago rasping machine constructed in this research

2.2. Experimental conditions
The parameters studied for rasping performance are hopper angle and teeth density on the cylinder surface. Hopper angle consists of three levels that are 0° (A1), 22.5° (A2) and 45° (A3) and three level of teeth densities i.e. 2.2 cm × 4 cm apart (D1), 2.2 cm × 3 cm (D2), and 2.2 cm × 2 cm (D3). Therefore, there were three cylinders each with different teeth densities (Fig. 2), in which each cylinder was subjected to three different hopper angle or slope (Fig. 3). In addition, the existing prototype (EP) was also tested. Cylinder rotation speed was set at 2250 rpm.

Figure 2. Three cylinder with different teeth density (left) and three levels of hopper angle (right) used for testing in this study

2.3. Rasping performance test procedure
The performance of each experimental condition in term of rasping capacity, starch percentage and starch yield were measured and evaluated. In the experiment, testing for each condition was repeated three times and the data were recorded. The performance tests of the experimental units were
conducted based on completely randomized design. A one-way ANOVA by SPSS Statistics (Version 23) was used for analyzing the data to determine the effect of independent variables on the dependent variables. A comparison between pairs of treatment means was made by determining the least significant difference (LSD) at 5% significance. The following procedure was used to test the rasping performance of each experimental condition.

2.3.1. Rasping capacity. The mature sago palm trees (*Metroxylon sago* Roth) which are ready for harvest were felled down using a chain saw. The felled sago palm trunk is then cut into shorter logs about 100 cm in length to facilitate transportation to the processing site. The first stage in the extraction of starch from the trunk is to separate the bark from the log. Once the bark is removed, the pith is split into pieces suitable for the rasping process. The pieces called billet are then fed manually onto the feeding plate and pushed gently to rotating cylinder. The pieces are fed onto cylinder with end-on direction. The rasped pith called repos [10], [11], [12]. Rasping capacity is determined according to equation (1):

\[ R_c = \frac{W_R}{t} \]  

(1)

Where \( R_c \) is rasping capacity (kg/h); \( W_R \) is weight of rasped pith/repos (kg); \( t \) is time required (hour).

2.3.2. Starch percentage. The rasped pith (repos) then was processed further using a stirrer rotary blade sago starch extractor [13], [14] to extract the starch. After pith disintegration, which aims to break down cellular structure and to rupture the cell walls, fiber and starch existed in the repos have not separated yet. The purpose of the extraction process is to separate the maximum amount of starch from the repos. Starch separation mechanism is that firstly repos is suspended in water and then stirred rigorously to release the starch. The suspended starch or starch slurry is then separated from the repos using a screen.

The starch extraction starts by feeding the rasped pith (repos) manually into the extractor. As much as 40 kg of repos was fed into the extractor in each experimental unit. A plenty of water was also being added and constantly supplied into the extractor while the extraction process is taking place to facilitate starch extraction. The stirrer rotary blade rotated at a fixed speed (100 rpm). While the stirring process is taking place, starch granules are forced to pass through the apertures of screen into the outer surface they then flowed to the sedimentation tank through pipe. This process was stopped when all starch had been washed out (no more starch in the repos), which was indicated by the slurry draining out from the extractor becoming clear. The resulting starch suspension in the collecting tank was left for sedimentation to allow starch particle to precipitate in the bottom of tank. Meanwhile, sago pith waste called hampas which is retained in the extractor was discarded out at the extractor gate. After 2 hours, supernatant water was drained out and the fresh or wet starch was taken and weighed. The starch percentages (wet basis) are obtained using equation (2):

\[ SP = \frac{W_S}{W_R} \times 100\% \]  

(2)

Where \( SP \) is starch percentage (% rasped pith); \( W_S \) is weight of starch (kg), \( W_R \) is weight of rasped pith (kg)

2.3.3. Starch yield. The starch yield is amount of starch that was resulted from extraction process. It depends on rasping capacity and starch percentage, and it is obtained using equation (3)

\[ SY = R_c \times SP \]  

(3)

Where \( SY \) is starch yield (kg), \( R_c \) is rasping capacity (kg/hour), \( SP \) is starch percentage (% rasped pith)
3. Results and discussion

3.1. Rasping capacity

Table 1 shows the mean values of rasping capacity, starch percentage and starch yield. The result of variance analysis showed that combination of hopper angle and teeth density (independent variables) had significant effect on rasping capacity.

| Hopper angle (degree) | Teeth density | Rasping capacity (kg/h) | Starch percentage (%) | Starch yield (kg) |
|-----------------------|---------------|-------------------------|-----------------------|------------------|
| 0° (A1)               | 2.2 cm × 4 cm (D1) | 1466<sup>b</sup>         | 44                    | 650<sup>b</sup>  |
|                       | 2.2 cm × 3 cm (D2) | 1147<sup>ab</sup>        | 33                    | 281<sup>a</sup>  |
|                       | 2.2 cm × 2 cm (D3) | 1294<sup>bc</sup>        | 35                    | 458<sup>ab</sup> |
| 22.5° (A2)            | 2.2 cm × 4 cm (D1) | 1348<sup>bc</sup>        | 38                    | 509<sup>ab</sup> |
|                       | 2.2 cm × 3 cm (D2) | 1891<sup>c</sup>         | 42                    | 790<sup>b</sup>  |
|                       | 2.2 cm × 2 cm (D3) | 1130<sup>ab</sup>        | 37                    | 427<sup>ab</sup> |
| 45° (A3)              | 2.2 cm × 4 cm (D1) | 1587<sup>cde</sup>       | 35                    | 561<sup>ab</sup> |
|                       | 2.2 cm × 3 cm (D2) | 1744<sup>de</sup>        | 35                    | 606<sup>ab</sup> |
|                       | 2.2 cm × 2 cm (D3) | 1211<sup>abc</sup>       | 40                    | 492<sup>b</sup>  |
| EP<sup>b</sup>        | 2.5 cm × 2.5 cm (DE)<sup>f</sup> | 839<sup>a</sup>         | 35                    | 302<sup>ab</sup> |
|                       | LSD 0.05        | 420 kg/h                 | NS                    | 419 kg           |

<sup>a</sup>Mean values with the same column followed by a same letter are not significantly different (P=0.05) according to Least Significant Difference Test (LSD).

<sup>b</sup>Existing prototype using cylinder covered with blunt end teeth.

<sup>c</sup>Using teeth density: the distance between adjacent teeth was 2.5 cm and between the teeth axes was 2.5 cm.

<sup>d</sup>Non-significant difference in LSD value at 0.05 level.

As shown in Table 1 that the highest rasping capacity (1891 kg/h) was obtained at condition A1D2 and the lowest one was at existing prototype (839 kg/h) which did not different significantly with A1D2 (1147 kg/h), A2D3 (1130 kg/h) and A3D3 (1211 kg/h). Generally, rasping capacity for all hopper angle increased as teeth density was increased from 2.2 cm × 4 cm apart (D1) to 2.2 cm × cm apart (D2) and then decreased. It means that teeth density D2 rasp more effective compared to teeth density D1 and D3. This was most likely related to the rasping torque requirement where the higher teeth density needs higher torque requirement and vice versa [15]. Darma et al. [16] found that that higher teeth density requires higher rasping power at the same cylinder rotation speed. The authors also found that the higher the teeth density, the higher the specific energy consumption. When the rasping torque requirement was lower, the feeding speed of sago pith onto rasping cylinder was higher and as a result was increased of rasping capacity. On the other hand, when the rasping torque requirement was high, the feeding speed of sago pith onto rasping cylinder was reduced and consequently, the rasping capacity was reduced. As the teeth density is increased further from D2 to D3, the rasping capacity decreases because of insufficient torque available on power source. Therefore, in order to maintain uniform cylinder rotation speed, the speed of feeding pith onto cylinder must be reduced otherwise the motor could overload. In extreme cases, the motor would be stopped and even become damage. In these conditions, pressing the sago pith too forcefully reduces the rasping capacity significantly [11]. Meanwhile, when the power source is large enough to surpass the cutting/rasping resistance of the sago pith, increasing teeth density probably not reduces rasping capacity. However, it is important not to press the sago pith too forcefully onto the cylinder surface, as this will seriously reduce the efficiency of the rasping machine. In addition, forcing material onto cylinder will result in coarser repos, fewer cells will be ruptured and more starch will be lost in waste.
Disintegration or breaking down the cellular structure of sago pith by means of rasping process, involving cutting and crushing. According to Sitkey [17], numerous factors affect the energy requirements/consumption of cutting, some of which are related to the mechanical properties of the material, while the others depend on geometry and adjustment of the cutting edge and on the kinematic conditions. The mechanical properties depend on the type of material, the stage of growth and moisture content, the location of cutting (close to the root or higher), etc. The thickness of the cutting edge (teeth) influences the cutting resistance in various ways. The greater the thicknesses of cutting edge the greater the energy required for cutting. A thickened edge consumes much surplus energy. With increasing edge thickness the additional deformation increases, whereby the energy required in cutting increases. A Rasping machine using multiple blades (teeth) in which every single teeth work independently as the cylinder rotate. The higher the teeth density mean more teeth engaged in any time, consequently required more energy.

Table 1 also shows that the higher the slope of hopper angles the higher the rasping capacity. This was because of more teeth engaged in any time at higher slope of hopper angle. The number of teeth involved at any time depends on the contact area between cylinder surface and sago pith is being rasped. The highest rasping capacity (1891 kg/h) that was resulted in this experiment is higher compared with previously study [18], [19], [20].

3.2. Starch percentage

The combination of hopper angle and teeth density did not affect significantly on starch percentage. The results shown that the starch percentage levels of all experimental condition were not significantly different. As it has been seen in Table 1, the starch percentage varied from 33 % to 44 % for all testing conditions. These results are consistent with previous study [16], however it higher than those of Darma et al., [15], [16], [21],[22], [23]. This is also much higher compared with those of Hermanto et al. [24], Irawan [25], Payung [26], Ratnaningsih et al. [27]. The higher starch percentage obtained in this experiment was due to the high starch content of sago pith that has been processed. Sago starch which is extracted from sago palm trunk not only depends on the method employed but also the starch content of the trunk. According to Rajyalaksmi [28], the variation in yield of sago palm has been attributed to biophysical difference or difference in management technique and as a result of differential skill and technology. Flach [2] reported that starch content of sago palm tree is around 10 % to 25 %. Meanwhile, according to Haryanto dan Pangloli [29], starch content in the sago pith is around 15 % to 25 %. Cecil [10] and Cecil et al. [11] also reported almost the same values (23% to 27%). Darma et al. [30] reported that starch content of sago palm in Papua province varies from 12.43% to 39.89 % (fresh weight). Singhal et al. [31] reported that starch content of the pith obtained from ready harvested sago palm varies from 18.8 % and 38.8% (fresh weight).

3.3. Starch yield

The different combinations of hopper angle level and teeth density were found to have significantly effect on starch yield. Comparisons among treatment means showed that the starch yield with the most treatments were not statistically different from each other, but differ with the combination of 0° hopper angle and teeth density of 2.2 cm × 3 cm (A1D2). Likewise, the lowest starch yield that was resulted at treatment A1D2 (281 kg) was not significantly different with the most others ones, except with the treatment of A2D2. The starch yield mean as showed in Table 1 was in the range of 281 kg to 790 kg. It is directly depend on rasping capacity and starch percentage. These results are consistent with previously study [16], [23]. Different trunk of sago palm contain different portion of both moisture and starch. The ratio of water to starch in sago pith depends on number of factors, some of which are inadequate understood. In very good stems/trunks there may be as much as 40 % of starch in the pith, but in average of between 30 % to 35 % might be expected [11]. Darma et al. [30] reported that some sago palm stems in West Papua Province contain less than 10 % of starch even some stems contain no starch at all. Starch yield varied quite considerably between researchers depending on the sophistication of the method applied and the starch content of sago pith that have been processed.
4. Conclusions
Combination of hopper angle and teeth density significantly affected rasping performance in term of rasping capacity and starch yield, while starch percentage was not affected significantly. The optimum combination to provide the highest performance was hopper angle 22.5° with teeth density 2.2 cm × 3 cm. The performance at the condition were (a) rasping capacity 1891 kg/hour, (b) starch percentage 42 % and (c) starch yield 790 kg.

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