Development and evaluation of sago (*Metroxylon sagu*) pith extractor

Jefrey M. Bagasbas,[1] Renyl B. Barroca[2]

[1]Department of Science and Technology, Philippine Science High School SOCCSKSARGEN Region Campus, Koronadal City; [2]Department of Mechanical Engineering, School of Engineering and Architecture, Ateneo de Davao University, Davao City, Philippines

Abstract

Among the significant problems in the sago processing, the extraction of the starch from its trunk tops the list. The extraction process involves a debarking and rasping process that is very tedious, unsanitary and time consuming that dramatically affects the quality of starch production since the local processor relies mainly on conventional method of extraction. This paper presents the design, fabrication and performance evaluation of sago pith extraction machine. The design concept made was to rasp the sago pith using a rotating rasper without debarking the log to minimize the steps on the extraction process. Four different teeth spacing of the rasper were considered during the testing and replicated three times; 1 cm, 2 cm, 3 cm, and no teeth as controlled parameters, respectively. Results revealed that teeth spacing has a significant effect on the performance of the machine such as extraction capacity, extraction efficiency and fineness of rasped pith. Based on average, the highest extraction capacity was recorded at 217.47 kg/h using 3 cm teeth spacing, and the highest extraction efficiency was 96.12% using 2 cm teeth spacing and the finest rasped pith having the lowest fineness modulus of 2.15 was when 1 cm teeth spacing is used. Compared to manual and other existing mechanical rasper accounting the process of debarking, machine's extraction capacity is higher, more efficient, safer and hygienic. Cost and benefit analysis supports that the machine is profitable and the financial efficiency is high having a 65% rate of return and 1.8 years payback period.

Correspondence: Jefrey M. Bagasabas, Department of Science and Technology, Philippine Science High School - SOCCSKSARGEN Region Campus, Brgy. Paraiso, Koronadal City, South Cotabato, Philippines.
E-mail: jefrey.bagasbas@gmail.com

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Introduction

Sago palm (*Metroxylon sagu Rottboell*) species is one of the most important sources of starch and is considered to be the earliest foodstuff of people that grow in swampy freshwater areas of South East Asia, some parts of Melanesia, the islands of Micronesia and elsewhere in the South America (Ave, 1977; Cecil, 1992; Flach, 1997). Etymologically, the term *sago* means the starch-bearing palm tree that originates from the Javanese word and in all the starch-bearing palms, the most unique feature from genus *Metroxylon* is the palms of the species sagu which has a characteristic of being hapaxanthic (once-flowering) and soboliferous (suckering) (Karim *et al.,* 2008), so after harvesting or cutting down the tree it will continue to grow through its suckers and bears another trunk that contains a huge amount of starch (Flach, 1997).

The stem of sago palm (from where the sago starch derives) is internationally called *rumbia* (Mustafa Kamal *et al*., 2017) and locally (in the Philippines) as *lumbia* (Flores, 2006); a huge trunk tropical plant with a maximum height of around 9-25 m depending on its kind (McClactchey, 2006) and diameter of 40 cm; with pinnate-leaves up to 9 m long; though it reaches commercial maturity after 9 to 12 years of planting (Mustafa Kamal *et al*., 2017). Some researchers stress that cultivated varieties in well-established plantations for *Metroxylon sagu* grow in 6-14 years (Ruddle *et al*., 1978) depending on soil conditions. The best thing about this palm is that it can flourish on a vast variety of soils like a well-drained and poor quality of sand and clay. The palm also tolerates salinity, successive flooding, acidic and wet soils (McClactchey *et al*, 2006; Karim *et al*., 2008) while naturally grow without putting pesticide or herbicide (Darma *et al*., 2014).

According to Ruddle *et al*., as the indicators by which sago palms are selected for harvesting are poorly documented, starch reserves are clearly at their highest level before its flowering season because, during the fruiting stage, these reserves will be depleted (Ruddle *et al*., 1978). Some researchers stipulated that chopping of sago palm in Indonesia and Sarawak palm is best carried out after flowering but before the fruiting stage (Flach, 1997).

The viability of establishing sago plantations, however, possesses significant challenges in terms of production, processing, product development, and marketing aspects. In the Philippines, sago palms are considered as a minor forest plant left in the swamp areas and almost forgotten. Since this palm is given only minor attention, some of the natural stands have been burned and destroyed to give way to other crops like rice and other cash crops. At the moment, sago is underutilised in the Philippines while in neighbouring countries like Indonesia and Malaysia it is considered as *staff of life* because of numerous uses (Flores, 2004; Mustafa Kamal *et al*., 2016).

There is a potential of sago palms in the livelihood systems of farmers in Visayas and Mindanao regions of the Philippines. An increasing area of production can be attained because of the presence of *excellent to very suitable* areas for sago plantation. Using the biophysical and bioclimatic characteristics, Santillan were able to estimate about 106,000 hectares for the Visayas and about 196,000 hectares in Mindanao areas for the sago production expansion (Santillan *et al*., 2013).

One of the main problems in the sago processing is the extraction of the starch from its trunk, and it involves a debarking and rasping process to extract sago pith (Singhal *et al*., 2007). In the current situation, the process of debarking and rasping process was being done both manually and mechanically. In conventional practice, readily harvested palms are selected and felled. The bark-like layer is stripped from the trunk and cut into sections or floated whole to a central processing facility. There, it is reduced to battens and rasped either manually or mechanically to pulverize the pith and loosen starch particles within the fibre. The starch is removed from the threads by kneading with hands or trampling by feet or by a spray of water. Starch-laden water or starch suspension runs into a settling container, where the starch is precipitated and the water overflows. The starch is then removed and dried (Kamal *et al*., 2007; Darma, 2015).

Debarking and rasping is a very tedious, unhygienic and time-consuming process that significantly affects the quality of starch being produced since the community rely mainly on their traditional method of starch extraction (Flach, 1997). In the conventional practice, the time required to process one trunk of Sago palm will take around forty-one (41) hours in which pith disintegration accounts around twenty-two (22) hours. Processing machinery of sago is considered one of the significant factors that limit its utilisation for several purposes.

There are existing machines that extract starch from the pith available in some regions in Mindanao. However, these machines perform debarking and rasping processes separately which makes them relatively expensive for the local processors to acquire. Integrating the two methods in a single procedure would be cost effective and cost efficient as it will reduce the losses in terms of energy and input materials while producing more significant number of output in a short period.

Hence, the objective of this research was to design, fabricate and evaluate a mechanical sago pith extractor that has an integrated debarking and rasping processes.

Materials and methods

Design of the sago pith extractor

Considering the physical characteristic of sago trunk the best way of extracting the sago pith and eliminate debarking process will be based on the combination of drilling and rasping of sago pith. After the log has been cut into several sections, approximately 50 cm in length appears to be cylindrically exposing the pith which is the soft part of the trunk on opposite ends. As the drill is in rotating motion the constrained sago log will move across the drill making its one end being penetrated. At the same time during the drilling process rasping happens simultaneously by subsequently touching the pith with the drilling element. The rasped pith will be collected in the bottom through a container ready for the next process.

The design of mechanical sago pith extractor as shown in Figure 1 comprised of operably interconnected four major components which are the body frame, the power transmission assembly, shaft assembly, and sago log holder. The body frame holds and supports other components. Majority of the materials in constructing the body frame were mild steel such as a hollow square tube and angle bars. Elements of body frame were rigidly attached through arc welding process to overcome the weight of other components as well as the fatigue and stress experienced by the material due to vibrations during the extraction process. Additional holes were provided at the bottom of leg support of frame assembly to insert a bolt as a means of fastening during the operation, and this will help to avoid the machine from moving due to vibrations. Rubbers were inserted in between the foot of frame assembly and the ground surface because it served as an active vibration absorbing element. The power transmission assembly drives the shaft assembly to create rotational movement. While the sago log holder secures the sago log while feeding the pith to the rotating shaft assembly.

In the design of shaft size, rigidity and stiffness of the shaft were considered. The shaft plays a significant role in the design as it carries the blade that will penetrate the sago pith while transmitting the power from the electric motor. The shaft was subjected to a combined bending and twisting moments due to the force created at the section where the sprocket is connected and due to the force when the blade penetrates the sago log as it rotates, respectively. The main shaft assembly plays a vital role in extracting sago pith from the trunk. It is made of 50 mm diameter solid stainless steel as calculated considering a safety factor of 2.5. Khurmi and Gupta state that the materials for the shaft must possess properties such as high in wear resistance, low notch sensitivity factor and good machinability in which stainless steel provides compliance with the requirements (Khurmi and Gupta, 2005). Stainless steel meets also the food grade requirement to avoid contamination of the rasped sago pith. Two pillow blocks rotatably secure the main shaft. The pillow blocks were bolted on the top of a rectangular platform. On the tip of the main shaft, multiple blades was mounted to punch the pith initially. A plurality of blades was adjustably mounted around the main shaft, its flexible nature is necessary to adjust its range depending on the diameter of the log being fed.

The log holder assembly consists of two circular frames that

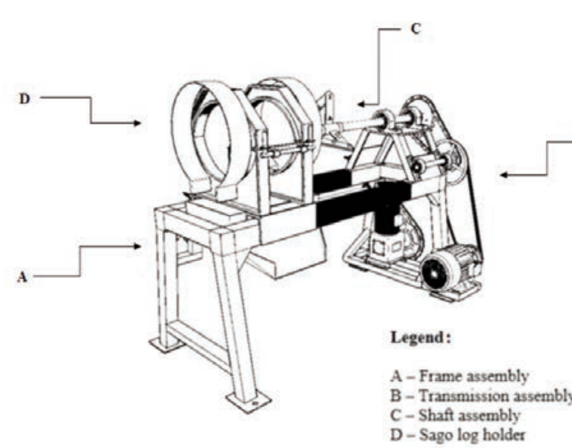


Figure 1. Design of sago pith extractor indicating the four major components, power transmission assembly, log holder assembly and the main shaft assembly.

holds and grip the sago log, two circular rings that prevents the rasped pith from scattering and adjustable knobs to accommodate different sago log diameters. The maximum and the minimum Sago log the holder can hold about 30 cm to 60 cm sago log diameter which is enough to cater different sizes of Sago log based on literature review and in the actual Sago log during the testing. The maximum length of sago log that the holder can accommodate is around 50 cm to 80 cm, however, considering the weight that a worker could carry, during the testing process, the 50 cm log length was considered. The shaft assembly will rotate in a fixed position while the log holder assembly driven by 0.37kW electric motor is traveling at a constant rate of 2.78 cm/min towards the tip of the rotating shaft under no load condition.

Drilling and rasping elements were the centres of the design as it reflects the performance of the machine in terms of capacity and efficiency. Isolated view of the driller rasper, and it was composed of multiple blades pointing on the centre was shown in Figure 2, this design helped the blades penetrate easily on the pith as it will require a small amount of torque at the tip of the knife. It was also designed in a manner of link bar members to facilitate adjustments based on the size of the trunk diameter. Food grade stainless steel materials were used to prevent contamination of the commodity. The blade can also be added with teeth at different spacing throughout the experiment to determine what types of rasper would give a better performance. Teeth were welded around the blade with different spacing such as 1 cm, 2 cm and 3 cm in relation to the study of Darma 2015. The adjustable mechanism was inspired in a four-bar linkage system. Adjusting the blade angles in the Figure 2 will also change the diameter created when the blade will revolve along the x-axis in line with the main shaft, this is to adjust based on the width of the sago log. Bolts and nuts supported adjustment mechanisms in the upper link while the lower links can be changed by loosening the nut and sliding along the shaft. The maximum diameter that the blade can accommodate is around 65 cm which is higher compared to the biggest log diameter of sago based on the literature.

Fabricated blades presented in Figure 3 consist of four variations to determine what will be the optimal spacing of teeth during the extraction process. Also, the teeth spacing have a significant effect on the fineness of the rasped pith. The drilling and rasping mechanism were designed to have a removable blade to replace the blades during the testing procedure easily.

Experimental set-up

There were four treatments implemented during the testing process that focused on the teeth spacing of the rasping blade, 1 cm, 2 cm, 3 cm and no teeth respectively. The rotational speed of the rasping blade was set at constant speed of 209 rad/s based on the study of (Darma, 2015) that gives the highest performance in terms of rasping capacity and efficiency, and to assess its performance of sago extractor, the four treatments were replicated three times that will sum up into twelve runs. The 209 rad/s angular speed of rasping blade was controlled by the variable frequency drive connected to and monitored using a tachometer. Sample material such as fresh sago log should be prepared uniformly to minimize if not eliminate the error or bias in the experimental procedure. Final testing was done after the machine has been polished and ready for data gathering. To achieve a good quality starch contained in sago pith, choosing of sago palm was considered carefully. The diameter of the palm should fit the machine's log holder diameter range. The more starch produced often found where the flowers are about to bloom. In choosing sago palm as test material, the age of the palm were carefully considered. Thus, sago palms that about to enter flowering stage were chosen. Once the sago

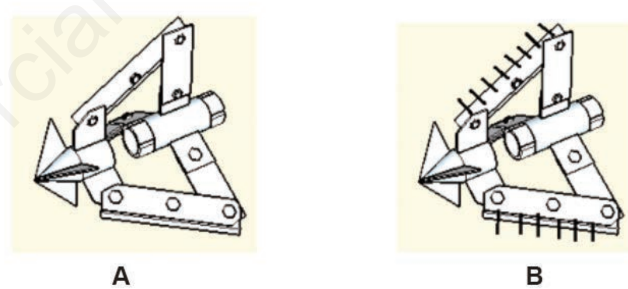


Figure 2. The blade assembly of mechanical sago pith extractor, (A) without teeth, (B) with teeth at different spacing.

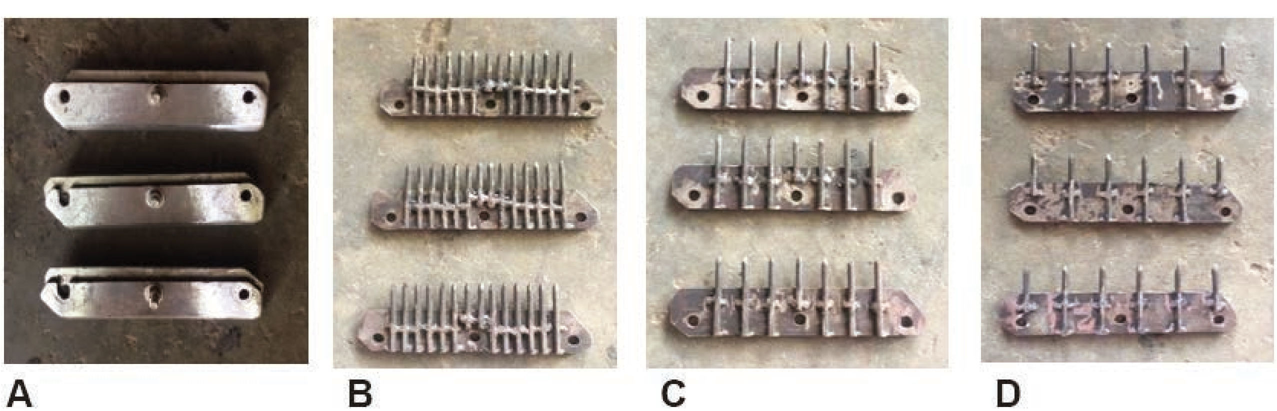


Figure 3. Blade variations considering teeth spacing, (A) no teeth, (B) 1 cm teeth spacing, (C) 2 cm teeth spacing and (D) 3 cm teeth spacing.

palm is chosen the next step was to fell the palm and then cut into shorter logs with a specific length of 50 cm using chainsaw. Logs that were measured 2 m from the ground were not included as test sample as this section would affect data on pith extraction. To start the process, the initial preparation of the machine is to check the level of safety by examining if the machine is in good running condition. All movable parts should run smoothly according to its function. The 50 cm log randomly selected was fixedly enclosed in the log holder assembly while traveling towards the rotating blade. During the set-up of the sago log, it was ensured that the centre of the log in longitudinal orientation was coincident with the centre point of the rasping shaft. The rasped pith then drops off under the discharge chute that facilitates and conveys the rasped pith into a container. The overall time of operation from loading the log in the log holder up to the completion of rasping process was recorded. Loading of the 50 cm log can be done by one person that takes about two to three minutes. The rasped pith in the container was weighed using a digital weighing scale for greater accuracy. Also, the rasped pith being scattered due to vibration and impact of the blade was also recorded to account scattering loss. After the pith inside the log has been rasped, the log will be discharged in the log holder. The remaining pith in the log will be scraped off manually using a bolo or knife and weighed after, and this is to account for the un-rasped pith that affects the extraction efficiency of the machine. A 500 g rasped pith sample for every run was analysed in a Tyler sieve to account for the fineness of the rasped pith.

Performance evaluation

Measuring the machine's performance plays a vital role in evaluating the machine to assess if it operates within the range of standards. There were three necessary performance that were assessed, the extraction capacity, extraction efficiency and fineness modulus of extracted particles of sago pith. Extraction capacity reveals how fast the machine could accomplish the targeted work while the efficiency manifests how pith extracted in the actual operation compared to the potential pith enclosed in the trunk. On the other hand, fineness modulus dictates the particles size of the extracted pith which has a positive correlation with the amount of starch recovered during the next stage of processing (Figure 4).

Extraction capacity

It is the amount of rasped pith being extracted with respect to the total operating time. This indicates the speed of the machine in accomplishing the task which is to extract the pith inside the log. This can be evaluated by getting the quotient of the weight of extracted pith against the overall operating time. Evaluation of extraction capacity (EC) was done through the formula:

$$EC = \frac{Wrp}{T} \quad (1)$$

where Wrp is the weight of the rasped pith (kg); T is the total operating time (hr).

Extraction efficiency

Extraction efficiency (Eeff) is the ratio of successfully rasped and contained pith over the potential amount of pith in the sago trunk sample. This defines how does the machine did the work considering the least possible time with a minimal waste. This was evaluated using the formula:

$$Eeff = \frac{Wrp}{P} \times 100\% \quad (2)$$

where P is the potential weight of pith inside the log (kg), can be determined by adding the weight of rasped pith (kg), weight of scattering loss (kg) and the weight of un-rasped pith (kg).

Fineness of rasped pith

Fineness modulus (FM) was used as an index to the fineness or coarseness of rasped pith. This is the summation of cumulative percentage of materials retained on the standard sieves divided by 100. The average particle size after the pith has been rasped and was determined using Tyler sieve.

$$FM=CPWR/100 \quad (3)$$

where CPWR is the cumulative percentage weight retained (%).

Statistical analysis

Data related to dependent variables, extraction capacity, extraction efficiency and fineness of rasped pith were subjected to one-way ANOVA to evaluate the significant difference ($P \leq 0.05$) among treatment means using four different teeth spacing at 1 cm, 2 cm, 3 cm and no teeth as controlled, respectively at constant angular speed of 209 rad/s. Tukey's *post-hoc* test was used to determine the specific differences between treatment means and to reveal the highly significant operating condition of the machine.

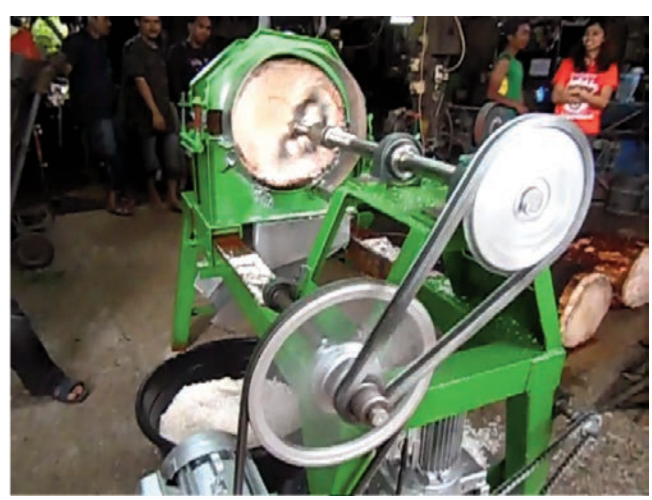


Figure 4. The actual extraction process of sago pith from the 50 cm sago log. The rasped sago pith was collected, weighed and sieved to evaluate the performance of the machine.

Economic benefits

Rate of return

The rate of return (ROR) is a method to measure the financial efficiency in order to justify the investment of capital. The ROR was evaluated using Equation (4), wherein the net annual profit was determined by having the total annual return from the extraction fee and subtracted by the total annual cost. The total annual cost includes fixed cost coming from depreciation, interest on investment, and tax and insurance. Sinking fund method was used for the calculation of the depreciation cost to account the inflation rate every year while 10% each from the investment cost reflects for the interest, repair and maintenance, and interest on investment. In addition to the total cost was the variable cost that comprised of energy consumption and the wages (Sta. Maria, 2000). Basic economic statement and assumptions for cost and return calculations were presented in Table 1. Considering the extraction capacity of the machine set at 200 kg/hr, although the average maximum capacity was 217.47 kg/hr, the estimated capacity for calculating economic benefit was safe enough since the desired operating condition was the performance of the machine with 2 cm teeth spacing as it would give a higher extraction efficiency and greater fineness modulus. The running time per day in which standard practice is at 8 h/day was set to an effective hour of operation at 6 h/day, and this is to compensate the time for adjustment and setting-up of the sago log in the machine and also for the loading of sago log and unloading of sago bark.

The estimated number of days of operation per month were assumed to be at 24 days throughout the 12 months in one year. The expected life of the machine was set to 10 years, according to Personal Property Manual 2016 of Nevada Department of taxation, the estimated life of agricultural machines and equipment is about 15 years (Nevada Personal Property Manual, 2016-2017) but according to Edwards 2015 of Iowa State University, a good rule of thumb to estimate the economic life of an agricultural machine is to use 10 years (Edwards, 2015). For the energy consumption, two electric motors were being used, one 2.24 kW and 0.37 kW motor operating for 8 hours a day having an electrical consumption of 17.90 kWhr and 2.98 kWhr respectively. The machine needs two persons to operate in which the operator has a higher salary compared to the assistant in compliance with the minimum wage of the Caraga Region that is 344.00 PHP per day. For the energy consumption, since the machine uses two electric motors (2.24 kW and0.37 kW), the price per kWh was set to 10.00 PHP based on the existing energy prices in the region with an annual increase of 1.07% based on Energy Regulatory Commission ERC (USAID-Philippines Final Report, 2013), because energy rate is fluctuating, this could also affect the revenue in operating the mechanical extractor. The income for the machine will be the payment for pith extraction which is set to 1.00 PHP/kg that is based on the fees for drying and milling machines, and this could also increase depending on the demand of the locality and the price of the electricity. The interest rate was considered at 7% annually based of GDP (Lema and Morales, 2018).

$$\mathrm{ROR} = \frac{\text{Net Annual Profit}}{\text{Investment Cost}} \mathrm{x}100 \tag{4}$$

Payback period

Payback period is a method to determine the length of time required to recover the initial cost. Some investors uses the payback period to make quick judgments about their investments. The Equation (5) was used to determine the payback period of the proposed sago pith rasper considering the average annual profit. The average annual profit was based on 10 years life of operation of the machine having its revenue from the extraction fee deducted by the total operating cost. Investment cost shown in Table 1 was the machine cost 78,000.00 PHP, wherein the salvage value that is estimated as 10% of the investment cost (Sta. Maria, 2000) will be deducted.

$$\text{Payback Period} = \frac{\text{Investment cost} - \text{Salvage value}}{\text{Average annual profit (P/A, i\%, n)}} \tag{5}$$

Table 1. Basic economic statements and assumptions for cost and return calculations.

Particulars	Quantity	Unit
Capacity of the machine	200.00	kg/h
Effective number of hours in operation per day	6.00	h
Number of days per month of operation	24.00	days
Number of months per year of operation	12.00	months
Cost of the machine	78, 000.00	PHP
Estimated machine life	10.00	years
Energy Consumption of 2.24 kW motor per 8 h operation	17.90	kWh
Energy Consumption of 0.37 kW motor per 8 h operation	2.98	kWh
Price per kWh*	10.00	PHP
Wage for operator per day	400.00	PHP
Wage for assistant per day	344.00	PHP
Extraction fee per kg rasped pith	1.00	PHP
Interest rate**	7.00	%

*Estimated energy rate in Mindanao with 1.07% average annual growth. **Based on the Philippine GDP's interest rate.

Results and discussion

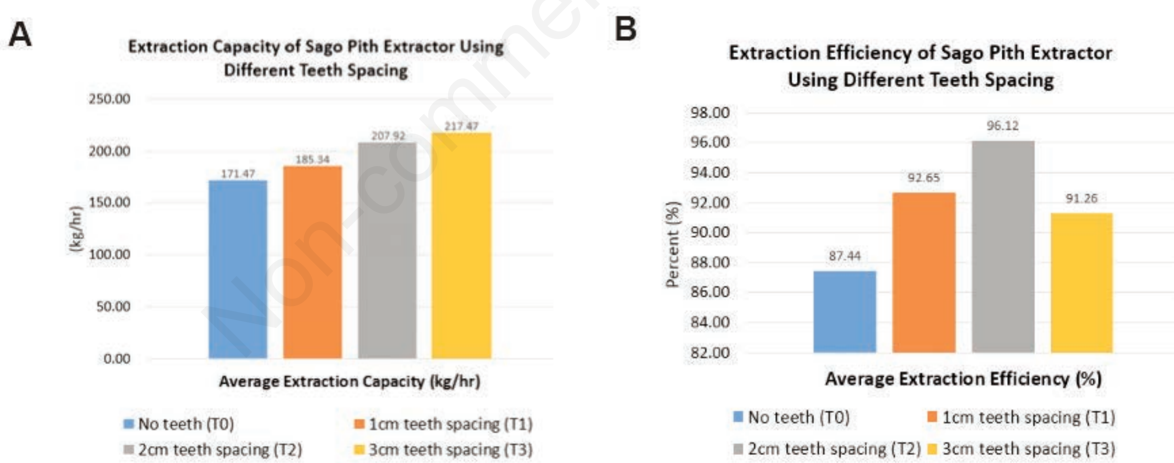
Extraction capacity

The relationship between extraction capacity and different teeth spacing at 209 rad/sec angular speed is shown in Figure 5A. It shows that the spacing of teeth minimizes the rasping capacity as it increases the point of contact between the pith and the teeth, therefore, increases the torque to overcome in turning the rasping blade. In the case of the blade without teeth, its contact with the pith is much higher as it gives the lowest average rasping capacity of 171.47 kg/h. This is consistent with the results (Anom, 2006) as cited by Darma (Darma and Istalaksana, 2011) which tested two different teeth spacing (1 cm and 2 cm distance) and also with Darma (Darma, 2015) which tested three different spacing (1 cm, 2 cm and 3 cm distance). The highest average rasping capacity was recorded at 217.47 using 3 cm teeth spacing almost twice as the rasping capacity from Loreto (Loreto *et al*., 2016) but slightly lower from the machine of Darma (Darma, 2015). Statistical analysis using One-way ANOVA reveals that there was significant difference among the treatment means. Tukey's *post-hoc* test shows that 2 cm and 3 cm teeth spacing were highly significant compared to 1 cm teeth spacing and no teeth respectively. Based on the trend, the extraction capacity will increase if there is an increase in the teeth spacing. Although it is expected that if we have additional treatment considering a teeth spacing of 4 cm, we will achieve greater extraction rate, but the fineness of the rasped pith will be compromised. As observed in the 3 cm teeth spacing, fineness modulus started to increase indicating that the particle size of the rasped pith increased. To increase the production rate of rasped pith, it is advisable to use lower teeth spacing as it reduces the torque requirement and so with the power requirement.

The sharp tip of the teeth also affects the performance of the machine; the frequent inspection must be done to maintain the teeth's sharpness. The teeth become dull especially when it has an excessive contact with the bark's surface. Therefore, it is necessary to adjust with the right amount of clearance not too close to the bark but not too far as it would also result from decreasing of machines extraction efficiency since more pith will remain to the bark un-rasped.

Extraction efficiency

The average extraction efficiency of different teeth spacing at 209 rad/s angular speed was shown in Figure 5B. The lowest and highest extraction efficiency were recorded at 85.52% from the blade with no teeth and 97.83% from the blade with 2 cm teeth spacing respectively. Analysis of variance exposed the significant difference with the mean extraction efficiency and it was uncovered by Tukey's *post-hoc* test that 2 cm teeth spacing was significant compared to 1cm teeth spacing and highly significant compared to 3 cm teeth spacing and no teeth respectively. Blades with no teeth has a difficulty of scraping those pith nearest to the bark, therefore, increasing the weight of un-rasped or un-extracted pith. On the other hand, 3 cm teeth spacing during the extraction process increases its scattering loss. To attain high extraction efficiency,



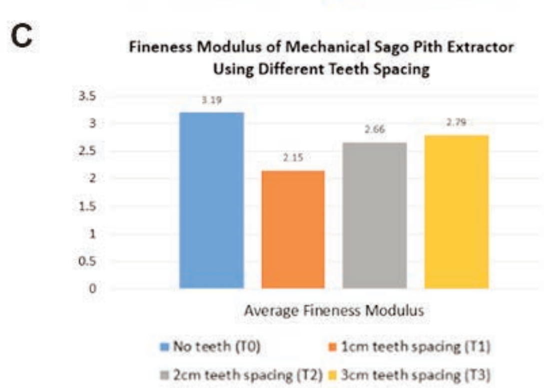


Figure 5. Machine's performance using different teeth spacing; (A) extraction capacity, (B) extraction efficiency and (C) fineness modulus of rasped pith.

based on observation, the clearance between the blade and the bark should be less than or equal to about 2-3 mm. The teeth being too close to the bark will shorten the utility of the teeth due to excessive wear and tear. Moreover, it was detected that the bottom part of the log around 2 m from the ground tends to get a lower extraction efficiency because the bark at this portion is thicker and consists of higher density fibrous matter with a more moderate amount of starch. Those fibres attribute to hasten the wear and tear of the teeth when exposed frequently (Loreto *et al*., 2006).

Fineness modulus

The lowest and highest fineness modulus shown in Figure 5C were recorded at 2.15 from 1 cm teeth spacing and 3.19 from no teeth respectively. Statistical test exposed that there was significant difference among fineness modulus means and *post-hoc* analysis further revealed that 1cm teeth spacing is highly significant compared to the three treatments while 2 cm spacing was significant compared to no teeth. The fineness modulus in this experiment was consistent with the results of (Bintoro, 2011) and (Darma *et al*., 2014) but disagrees to the result of (Loreto *et al*., 2006). The pointed tip of the teeth dramatically affects its performance in hammering the pith. The blade with no teeth recorded for the highest average value of the fineness modulus, it has been observed that it does not rupture or pounded the pith but sliced and scraped. Although increasing the teeth spacing has a positive effect by increasing the extraction capacity, it will have a negative impact on the quality of the rasped pith as results to bigger particle size, thus minimizes the amount of starch that will separate the pith on the latter stage. Based on the data teeth spacing in between 1 cm to 2 cm will provide a desirable operating condition as far as extraction capacity, extraction efficiency and fineness modulus are concerned.

Economic benefit

The rate of return of the mechanical extractor was shown in Table 2. Based on the given data the computed total annual cost for the operation was 295, 210.00PHP that includes the fixed cost and variable cost. On the other hand, the total returns annually based on the payment for pith extraction could reach up to 345, 600.00 PHP considering the constant supply of sago logs.

The calculated rate of return was about 65% which is much higher than the interest rate on lending facilities of 4.5% as of December 2019 (BSP, 2019), and this indicates that annually you can get 0.65 PHP in every 1.00 PHP investment, it is therefore economically viable considering the optimistic value based on assumptions stated in Table 2. In case of considering a scenario wherein the operation will be reduced into half of its annual capacity, the rate of return will drop at 18.96% which is still higher than the interest rate in this case, the machine is still profitable. Considering the gross benefits or returns for ten (10) years, the total cost and the initial cost of the machine a payback period of 1.8 was derived, this means that the invested capital of 78,000.00 PHP could be recovered as early as two years considering the consistency of the situation stated and assumed.

Table 2. Mechanical Sago pith extractor's rate of return.

Fixed cost		PHP
	Depreciation (sinking fund method)	5, 203.85
	Interest on Investments (10% of machine cost)	7, 800.00
	Tax and Insurance (10% of machine cost)	7, 800.00
Total fixed cost	20, 803.85	
Variable cost		
	Energy consumption	60, 134.40
	Wages	214, 272.00
Total variable cost		274, 406.40
Total annual cost		295, 210.25
Returns		
	Extraction fee for the sago pith annually	345, 600.00
Total annual returns		345, 600.00
ROR (%)	65.00	

Conclusions

This study has intensively and widely expanded due to a high demand to have an efficient, cost-effective, environmentally friendly mechanical sago pith extractor that will be used by sago farmers to increase and boost productivity and enhance the quality of sago starch products. The mechanical Sago pith extractor that integrates rasping and debarking process was designed and fabricated. The machine was tested and the performance was evaluated based on three parameters, extraction capacity, extraction efficiency and fineness of rasped pith respectively.

A comparison of the results of the three different teeth spacing of the rasping blade and no teeth as controlled shows that by adding teeth space results to progressive increase of the extraction capacity, although there is a tendency to decrease the extraction efficiency between 2 cm teeth spacing (96.12%) and 3 cm teeth spacing (91.26%). Considering the fineness modulus, the 1 cm teeth spacing is the most favourable having the lowest recorded value (2.15). Based on the data, the recommended teeth spacing is 1cm and 2cm respectively. Future researches are aimed to determine if there will be significant difference on the starch extracted between 2cm and 3cm spacing and also a study to determine the optimum operating conditions is also recommended considering the three factors, different shaft rotational speed, different teeth densities and different speed of log holder or the feeding rate of the sago log.

The mechanical sago pith extractor performed better extraction capacity and higher extraction efficiency than the manual method and other existing machines. It is comfortable and safe to operate and does not need a highly skilled operator to run the machine. The hazard of contamination was minimize compared to manual and other methods as it eliminates the debarking process. Moreover, the machine has a reasonable cost and can be fabricated in a local fabrication shop. Lastly, cost and return analysis and payback period supports that the mechanical sago pith extractor is highly profitable and capital invested can be quickly recovered.

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