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<https://doi.org/10.5109/5909108>

出版情報 : Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 8, pp.303-310, 2022-10-20. Interdisciplinary Graduate School of Engineering Sciences, Kyushu University

バージョン :

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Design, Fabrication, and Performance Evaluation of Sago (*Metroxylon sago* Rottb.) Starch Extractor

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Abstract: This study was conducted to evaluate the performance capacity of the fabricated mechanical sago starch extractor based on the effect of the application of different ratios of water versus inputted sago pith. Three (3) treatments were examined in the experiment, such as 5 kg of rasped pith with 5 L of water, 5 kg of rasped pith with 10 L of water, and 5 kg of rasped pith with 15 L of water using the same speed at 323 rpm. The result shows that the more water added to the rasped sago pith, the highest starch recovered with 32.1% to the 5 kg rasped pith with 15 liters of water mixtures, thus resulting in 160.72 kg/day starch yield. Using Analysis of Variance, RCBD, the level of significance was determined. Hence, the Sago Starch Extractor machine is recommended for small to medium-scale processing with 96.3% extraction efficiency.

Keywords: input capacity; pith; starch recovery; starch yield; sago starch extractor;

1. INTRODUCTION

The sago palm is a species of the genus *Metroxylon* that belongs to the *Palmae* family. Sago is purely Javanese, meaning starch-containing palm pith. The scientific name comes from “metra,” which means pith or parenchyma, and “xylon” meaning xylem. It is indigenous to South-East Asia and inhabits freshwater swamps and moist rainforests.

Several studies have been made for the development of the cultivation of sago palm. Some crop production can exist around Asian countries in Singapore, West Malaysia, and Indonesia. [1].

In the Philippines, the Visayas and Mindanao Islands have the area for sago palm plantation located in Agusan del Sur in the Northeastern part of Mindanao. It has the most extensive site of Sago palm production. It is estimated to be 600-650 hectares from Agusan del Sur, followed by 29.75 hectares from Agusan del Norte [2,3].

Sago has long been an important food staple due to its sources of nutritional value. The main product of this crop is sago starch. It is the source of food for some native people in various areas. The palm has potential for several uses, including food and nonfood uses. The leaves can be use in making house accessories and roofing. The high amount of starch in the trunk are useful for biofuel, flooring, walling, furniture, and wooden décor. The important usage of this crop in food processing involves food and beverages products. [4].

In recent studies, there are methods have been reported for sago starch extraction. The development of sago starch extractor with stirrer rotary blade and combined processing of sago palm plant in other Southeast Asian countries like Indonesia, Malaysia, and Papua New Guinea [5,6]. Hence, in the Philippines, no modern equipment has been commercialized in the extraction of Sago starch.

It has known that the traditional method of sago starch processing is a time and labor-intensive process. Sago starch production is very low, both in quantity and quality. Farmers in this area continue to use traditional systems to process sago starch because of the lack of mechanical equipment. The industrial technology of

processing starch and its derivatives from potato, cassava, maize, rice, and wheat has developed very well. There are only a few simple technologies besides the traditional method [7,8,9].

To meet the challenges, it is necessary to conduct research specifically on the mechanization of sago starch extractors to lessen the manual extraction of sago starch efficiently, considering the separation of extracted starch from the pith and the residue for other purposes.

Extraction of sago starch from pith is critical in sago starch processing. The study was conducted to mechanize equipment in the extraction processes. This study aimed to design, fabricate and evaluate the performance of a sago starch extractor that is affordable and time-saving in operation.

The study's general objective was to design, fabricate and evaluate the performance of the Sago Starch Extractor. Specifically, it aimed to

1. Design and fabricate a sago starch extractor.
2. Evaluate sago starch SSE's performance in input capacity, starch recovery, meal recovery, extraction rate, recovery, and losses; settling capacity; potential starch content; and extraction efficiency.
3. Evaluate its economic benefit to the users.

Sago starch is produced from sago palm. It is a food staple of most people in the villages [10,11,12]. The traditional methods of extraction are still being used today. The starch processing technology is vital to minimize labor expenses and time consumption. The production of starch is necessary to be able to supplement the need of humans for food consumption and other uses [13,14,15,16,17].

The need to design and fabricate equipment for the extraction of starch to be used by most native people around the country or for income generation is necessary. Also, commercial uses include the faster production of sago starch. This fabrication of the extractor would apply to the users and consumers. The basic concept for a sago starch extractor is an extractor that can be functional and user-friendly and cater to users' sago extraction

processes. The mechanism would be the rasped or shredded pith from sago will be fed in the hopper with the aid of the water, then it passes through in the extracting chamber where the extraction occurs. Then the extract and the *hampas* would separate. The extract will flow directly into the settling tank, where sedimentation processes occur.

This study focused on the design, fabrication, and performance evaluation of sago starch extractors in terms of applying different ratios of water added in the pith versus input rasped sago pith to separate the starch from determining capacity and efficiency. It used shredded or rasped sago pith as the source of starch and water to facilitate the extraction of starch at 323 rpm. After the extraction, sedimentation processes occurred in the settling chamber and assessed its recovery time.

2. MATERIALS AND METHODS

2.1 General Methodology

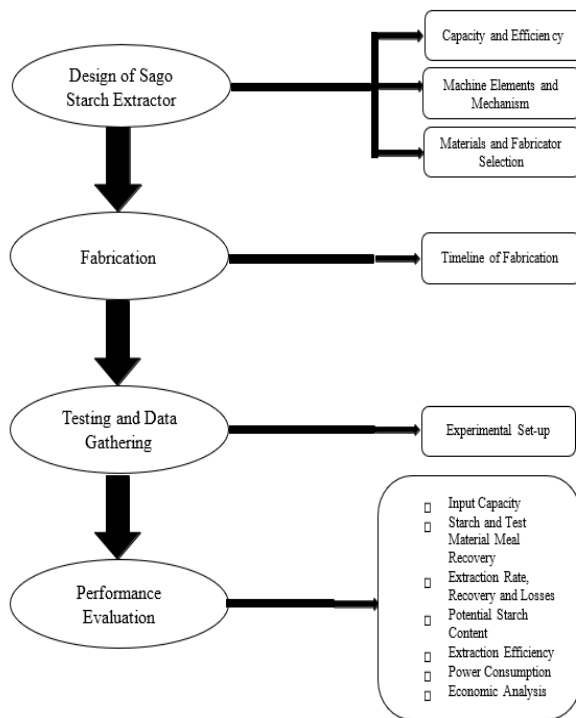


Fig. 1. General Methodology

Figure 1 shows the general methodology involved in the study. There were four (4) processes involved in this research. The first process was the finalization of the designed Sago Starch Extractor (SSE) by designing its capacity to extract sago starch, including the machine elements. Then, the selection of food materials were significant to secure food safety standards and the quality of the machine in operation.

The following study process was the fabrication stage of the designed Sago Starch Extractor. It was necessary to select the best fabricators in the fabrication process to obtain the quality of the machine. The third process was testing and data gathering using the fabricated machine. The machine adjustments were performed after testing and observing some defects, discrepancies, and errors during fabrication.

In the performance evaluation, the methods involved were measured by evaluating the parameters for input capacity, starch recovery, test material meal recovery, extraction rate, recovery and losses, extraction efficiency, and its economic benefits.

2.2 Design of Sago Starch Extractor (SSE)

The Sago Starch Extractor (SSE) was designed as a user-friendly machine because it only requires minimum labor, made of cost-efficient food-grade materials. SSE comprises different parts: water tank/storage, hopper, extracting chamber, meal and extract outlet, shafting assembly, electric motor, frame, settling/ storage area, meal storage, and mesh.

As shown in Figure 2, the machine was designed to extract sago starch from the rasp pith efficiently. The pith was continuously fed in the hopper with water from the water tank above the chamber for extraction. The chamber has a mixing blade fabricated at a five (5) degrees position and a spiral blade that will facilitate starch extraction. The mixing blade will chop the pith into smaller pieces and releases it into the spiral blade for extraction. After the extraction, the extract will flow into the settling box through gravity. The settling capacity of the starch was assessed to determine the settling time.

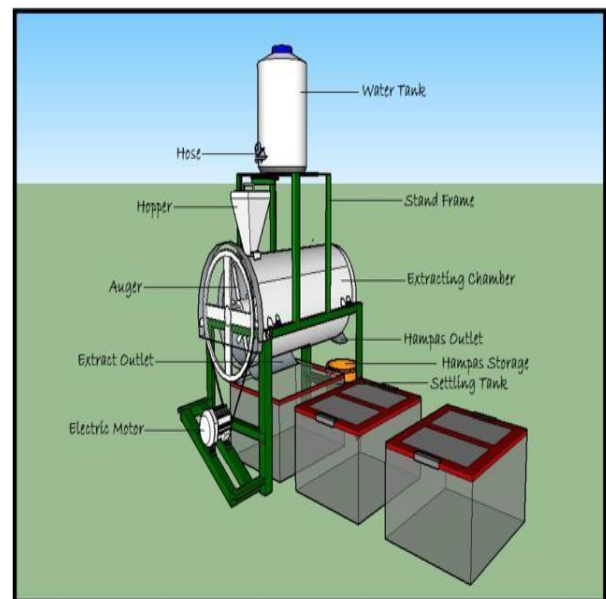


Fig. 2. Sago Starch Extractor

2.3 Machine Elements and Consideration

The machine was composed of extracting chamber, water supply storage, settling tank, and hampas storage. The sago pith was continually feeding to the hopper while the calibrated volume of water was mixed. The mixtures of water and pith had moved through the extractor blade for the extraction process. The extract passed directly in the sieve into the settling tank while the hampas collector collected the meal.

2.4 Machine Elements and Consideration

The materials used in the machine must be food-grade material, especially in the extracting chamber, the auger blades, mesh, and hopper. Testing and adjustments were

emphasized. Its part would be cleaned easily for the next user. The extract outlet was created that can easily open and close.

2.4.1 Water Storage

The water storage was just above the hopper at the center part of the cylindrical chamber. The water storage can carry up to 25 L of H₂O. It will give the supply of water in the extraction of starch. The water fed in the extracting chamber was equal at a ratio of 1 L/ min for treatments A and B while 1.5 L/min for treatment C.

2.4.2 Hopper

The hopper was just at the upper left portion of the extracting chamber. It has dimensions of 8.5 inches in length, 3.5 inches base1, and 8 inches base2. It can carry 1kg of sago pith to be fed in the chamber. It was made up of a stainless-steel Grade No. 316 welded by a stainless steel rod.

2.4.3 Extracting chamber

The extracting chamber was composed inside of the auger blades and mixing blades. It was made of stainless steel Grade No. 316 for food safety. It has a diameter of 9 inches and a length of 21.5 inches. The extraction occurred in this chamber through the blades. The blades are designed for mixing and extracting sago starch.

2.4.4 The Auger

The auger was made by stainless steel Grade No. 316. The mixing blade was made at 5 degrees for mixing the rasped pith as it enters in the chamber and pass in the spiral blades for extraction.

2.4.5 Shafting Assembly

The Shafting assembly was just at the left portion of the extractor. The pulley had a length of 54 inches. The folia has 16 inches in diameter and the driver shaft is 3 inches in diameter. The folia was made of cast iron. It would help in the extraction process.

2.4.6 The settling tank

The settling tank was just under the extracted outlet. The material is made of BPE-free plastic. It has the capacity to store the extract at about 30 L liquid.

2.4.7 The settling tank

The hampas storage served as the storage of the meal that would pass through from the extracting chamber. It has the capacity to store about 15 kg of the meal.

2.4.7 Fabricator and Material Selection

The researcher canvassed at least 5 fabricators who worked in the known engineering works and industries of Butuan, Bayugan and San Francisco. After finding the fabricators, the researcher chose the best fabricator to be made the machine functional. The researcher chose Pete Lim's Industry to make the machine. After the researcher deals with the fabricator the contract of agreement for thesis fabrication was done. Testing and adjustment, labor and material cost were also agreed by both parties.

The material was bought at Pete Lim's Industry because they sell a material for fabrication.

2.5 Fabrication of the Machine

Six months' timeline of activities was considered in the study. The finalization of the design was done in the month of November. Canvassing of materials and fabricator was followed and the billing of materials in March 2021. The fabrication of the machine had consist of 2 months with allowance, February to March. Testing and Adjustments was next after fabrication. The Performance Evaluation is also important to determine the capacity and its efficiency which was done from April to May 2021.

2.6 Testing and Data Gathering

2.6.1 Experimental Set-up

The performance of the extractor was determined using 3 different volumes of H₂O added with rasped sago pith at equal weight of 5kg in three (3) trials. Treatments A, B and C were used, where A has 5 kg of rasped sago and 5 L of H₂O; B has 5 kg of rasped pith and 10 L of water and C has 5 kg of rasped pith and 15 L of H₂O, respectively. Data for the trial was recorded from the operating time water discharge and starch recovered were recorded.

2.6.2. Data Gathering

The prepared test samples was 5kg of rasped sago pith and the H₂O. Trial treatments assigned as T1, T2, and T3. The total extraction time was recorded, including the settling time. A data sheet was used to record the gathered data immediately.

Upon data gathering, in every treatment, the 1kg of rasped pith must feed first at 1 minute before adding it with water, thus resulting to the ratio of 1 kg of rasped sago pith inputted per 1 minute and 1 L of water per 1 minute for treatment A while treatment B there is 0.5 kg of rasped sago pith inputted per 1 minute and 1 L of water per 1 minute and in treatment C there is 0.4 kg of rasped sago pith inputted per 1 minute and 1.5 L of water per 1 minute.

2.7 Performance Evaluation

This was used in the evaluation of the capacity of the SSE to extract starch. Input capacity, starch and meal recovery, extraction rate, losses and recovery, potential starch content and extraction efficiency formulas were used in determining the machine's capacity and efficiency. Also, electric consumption was measured [18].

2.7.1 Input Capacity

It refers to the capacity of the machine to extract with respect to the amount of material being inputted. It was measured by the ratio of the weight of input material to the time required to empty the hopper of the input material. This was measured using the following formula [8]:

$$Ci = \frac{wi}{Ti} \quad (1)$$

Where:

Ci = Input Capacity, kg/h

Wi= Weight of input material, kg
Ti= Time required to empty the hopper of the input material, hr

2.7.2 Starch Recovery

It is the ratio of the weight of the extracted starch collected from the settling storage to the weight of the input material. The following formula was used in determining the starch recovery [8].

$$Ro = \frac{wf}{wi} \times 100 \quad (2)$$

Where:

R_o = Starch Recovery, %
Wf = Weight of extracted starch collected from settling storage, kg
Wi = Weight of input material, kg

2.7.3 Meal Recovery

It is the recovered meal from the inputted material. It is measured by the ratio of the weight of the meal collected to the input capacity multiplied by 100 [8].

$$Mr = \frac{wm}{wi} \times 100 \quad (3)$$

Where:

Mr = Test material meal recovery, %
Wm = Weight of meal collected, kg
Wi = Weight of input material, kg

2.7.4 Extraction Rate

It is the quantity of juice that the extractor can obtain per unit of time. It is measured using the ratio of the weight of starch collected and supernatant water to the total operating time.

$$Er = \frac{wf}{Tt} \times 100 \quad (4)$$

Where:

Er = Extraction rate, kg/hr.
Wf =Weight of starch collected and supernatant water, kg
Tt = total operating time, hr.

2.7.5 Extraction Losses

It is the amount of starch collected at the hampas. It was measured using the ratio of the weight of the starch collected other than from the extract to the total weight of the extracted starch [8].

$$El = \frac{wl}{wts} \times 100 \quad (5)$$

Where:

El= Extraction losses, %
Wl = Weight of starch collected other than from extract outlet, kg
Wts = Total weight of extracted starch, kg

2.7.6 Extraction Recovery

It is the amount of extracted starch collected based on the extraction losses. It is measured by subtracting 100% to the extraction losses in terms of percentage.

$$Er = 100 - El \quad (6)$$

Where:

Re = Extraction recovery, %
El = Extraction Losses, %

2.7.7 Potential Starch Content

It is the starch collected from the settling storage and also starch collected from hampas. Potential starch content was measured by total starch recovered from input material added with the starch recovered from hampas.

$$Psc = Is + Hs \quad (7)$$

Where:

Psc = Potential starch content, kg
Is = Total starch recovered from input material, kg
Hs = Starch recovered from hampas, kg

2.7.8 Extraction Efficiency

It is the ratio between the total weight of extracted starch abd the potential starch content. The data was measured also in terms of efficiency. The following formula was useful in determining the efficiency.

$$Eff = \frac{wts}{Psc} \times 100 \quad (8)$$

Where:

Eff = Extraction efficiency, %
Wts = Total weight of extracted starch, kg
= Wf + Wts
Psc = Potential starch content, %

2.7.9 Electrical Energy Consumption

The SSE electrical consumption using the following formula. It is the ratio of the power consumption to the weight of the input material.

$$Ec = PcTo / Wi \quad (9)$$

Where:

Ec= Electrical energy consumption, kW-h/kg
Pc= Power consumption, kW
To= Time of operation, h
Wi= Weight of input material, kg

2.8 Statistical Tool

The researcher used Analysis of Variance (ANOVA) using Microsoft Excel. To analyze the data gathered during the process the researcher used single factorial experiment Randomized Complete Block Design and it was supported by Duncan's Multiple Range Test (DMRT).

2.9 Economic Analysis of the Sago Starch Extractor

The economic analysis was determined by calculating the Depreciation, ROR, Payback Period, and Salvage Value [19].

2.9.1 Depreciation

It is the decrease in the value of a physical property with the passage of time. It is computed using its formula in Equation 10.

$$\text{Depreciation} = \frac{IC-SV}{\text{Lifespan}} \quad (10)$$

Where:

Investment Cost(IC) = total unit cost of the machine
Salvage Value(SV) = 10% of investment cost
Lifespan = 10 years

2.9.2 Return on Investment

Return on investment or ROI was used to evaluate the efficiency of an investment and was given by Equation 11.

$$ROI = \frac{\text{Annual net Profit}}{\text{Amount of capital invested}} \times 100 \quad (11)$$

Where;

Annual net profit = Annual Income – Annual Expenses
Total Annual Cost = Operational Cost + Taxes and Maintenance

2.9.3 Payback Period

It is defined as the length of time required to recover the first cost of investment. Equation 12 is used in the computations [9].

$$\text{Payback Period} = \frac{IC-SV}{\text{Net Annual Cash Flow}} \quad (12)$$

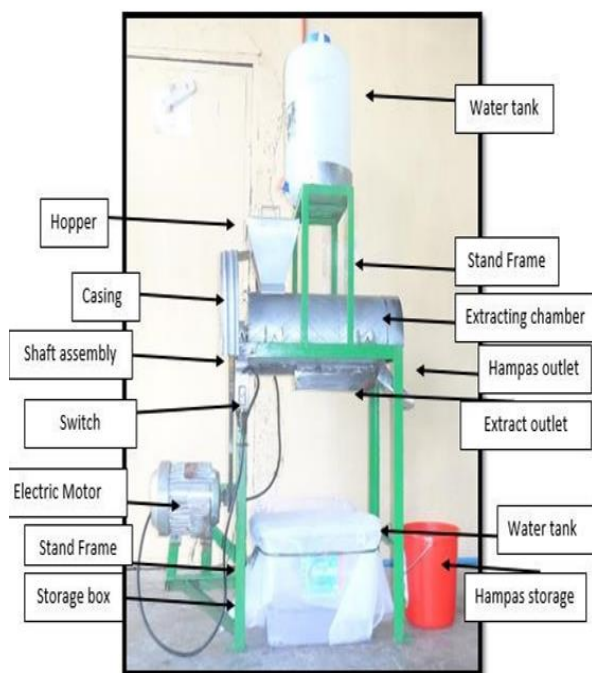


Fig. 3. Actual Photo of Sago Starch Extractor

3. RESULTS AND DISCUSSION

3.1 Fabrication of the Machine

Figure 3 shows the actual photo of the fabricated Sago Starch Extractor. The extractor was composed of the

water tank that supplies water and facilitates the extraction. In the lower left part of the machine is the 2 horsepower(hp) electric motor. The designed speed was 323 rpm. Increasing the speed will cause too much heat in the extracting chamber due to friction in the auger blades while decreasing of speed will cause low extraction of the starch-based on the adjustments.

Figure 4 shows the actual photo of the auger blades inside the chamber. This blade served as the essential component of the machine as it facilitated the faster extraction process of the sago starch. It is composed of mixing and spiral blades. It is one of the most critical parts of the machine. The materials used were made up of stainless steel for food safety. The blades were positioned at a five (5) degrees angle. This screw type blade attached in the chamber can be cleaned manually after the operation.



Fig. 4. Actual Photo of the blades inside the chamber

3.2 Performance Evaluation

3.2.1. Input Capacity

The input capacity of the machine was measured using three (3) treatments with three trials. Based on the result, Treatment A had the highest average input capacity with 77.5053 kg/hr. while Treatment B had the lowest input capacity with 62.803 kg/hr.

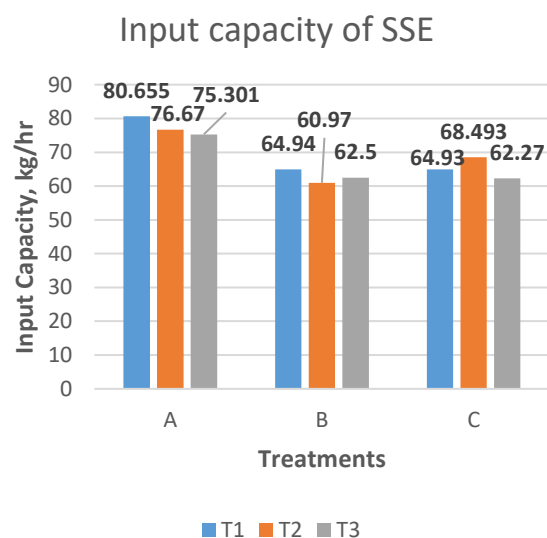


Fig. 5. Input Capacity

It shows that among the three treatments, treatment A has the higher input capacity. To determine the level of significance between treatments, ANOVA was used, and research found that it was highly significant as shown in Table 1. Moreover, Duncan's Multiple Range Test (DMRT) was used to determine which treatment was significant and the result is shown in Table 2. It was found out that Treatment A is significant to Treatment B and C at 5% level. Treatment B and C was not significant with each other since their treatment means had the same letters.

Table 1. ANOVA of the Input Capacity of SSE

Sources of Variations	Degrees of Freedom	Sum of Squares	Mean Square	Computed F	Tabular F	
					5%	1%
Treatment	2	374.25	187.125	25.99**	5.14	10.92
Error	6	43.17	7.20			
Total	8	417.42				

Table 2. DMRT Analysis for SSE's Total Input Capacity Performance

Treatment	Mean	Rank
A	77.5053 a	1
B	62.803 b	3
C	65.231 b	2

Note: The same letters are not significantly different from each other.

3.2.2 Starch Recovery

The starch recovery of the machine was measured by getting the weight of the extracted starch collected after the sedimentation process and the result is shown in Figure 6.

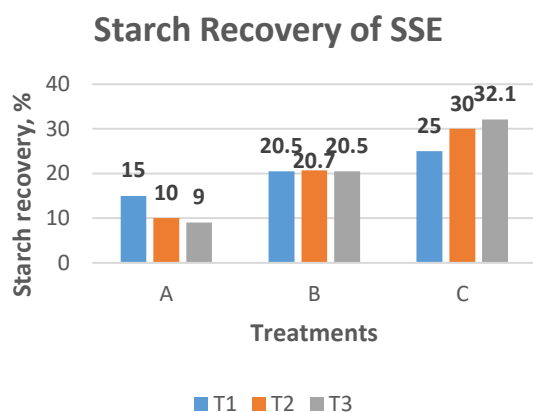


Fig. 6. Starch Recovery

Based on the result, Treatment C recorded the highest recovery with 32.1%, 30%, and 25% at Trial 3, Trial 2, and Trial 1, respectively. On the other hand, treatment had the lowest recovery of 15%, 10%, and 9% at Trial 1, Trial 2, and Trial 3, respectively. Hence, the more water applied to the sago pith the highest the starch recovery.

3.2.3 Extraction Rate

The extraction rate of the machine was determined by measuring the weight of the collected supernatant water and wet starch during the total operating time and the results are shown in Figure 7.

Based on the results, the highest extraction rate was found at Treatment B at 44.26 kg/hr. while the lowest extraction rate was at Treatment A with 23.06 kg/hr. To determine the significance level of the SSE among treatments, an Analysis of Variance using RCBD was used. Based on the result as shown in Table 13 that it was highly significant since the computed F was greater than the tabular F at 95% and 99% levels of confidence.

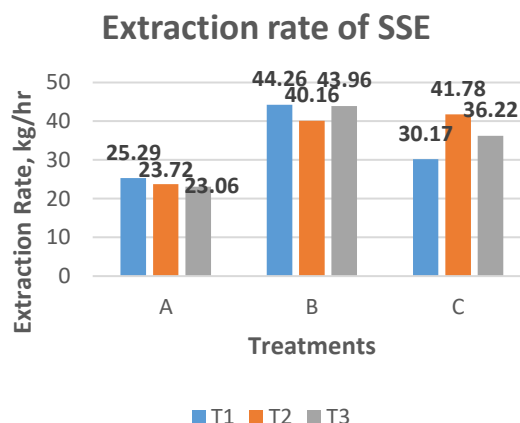


Fig. 7. Extraction Rate

Table 3. ANOVA of Extraction Rate of SSE

Sources of Variations	Degrees of Freedom	Sum of Squares	Mean Square	Computed F	Tabular F	
					5%	1%
Treatment	2	633.07	316.54	17.45**	5.14%	10.92%
Error	6	108.84	18.14			
Total	8	741.91				

**highly significant

Moreover, DMRT Analysis was used to determine which treatment had significantly different and the result is shown in Table 4. Based on the result, Treatment A and Treatment B had significantly different while Treatment C had no significant difference from Treatment A and B.

Table 4. DMRT Analysis of SSE for Extraction Rate

Treatment	Mean	Rank
A	24.02 b	3
B	42.79 a	1
C	36.07 ab	2

3.2.4 Extraction Efficiency

The extraction efficiency of the Sago Starch Extractor was measured, and the result is shown in Figure 8. Based on the result, the machine was efficient among all treatments with an average efficiency of 95.07%, 93.85%, and 87.29% at Treatment B, Treatment C, and Treatment A, respectively.

3.2.5 Economic Analysis

3.2.5.1 Rate of Return

The rate of return was defined as the measure of the financial efficiency of the investment in order to justify the investment capital. The rate of return of the SSE was 102% as shown in Table 5. The 102% simply means that the return cost is 1.02 times the investment annually. The machine price was estimated only for the development cost, and it can be changed based on the materials used and selection.

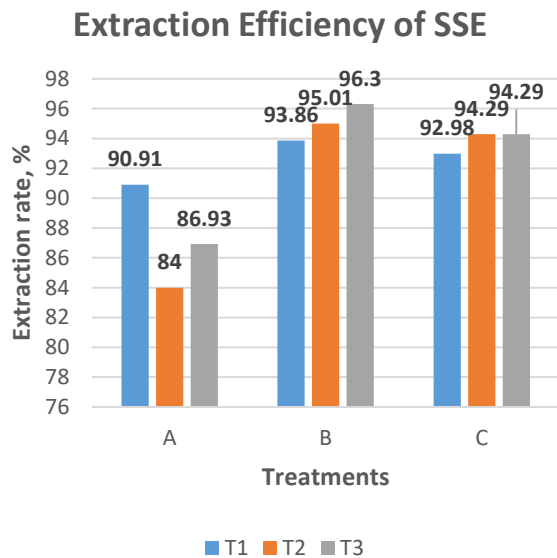


Fig. 8. Extraction Efficiency

Table 5. ROR for different treatments.

Total Unit Cost	Profit	ROR
Php 29,559	Php 30,213.65	102 %

3.2.5.2 Payback Period

The payback period defined as the length of time required to recover the first cost of investment. It was assumed that the operation per day was 8 hours to recover the cost of investment with 240 working days. The investment of the machine will be recovered at 10 months.

4. CONCLUSION

The result concluded that the machine is economically suitable for small and medium sago starch processing. The machine was highly significant in Treatment B (5 kg of rasped pith: 10L of water) in terms of starch recovery and efficiency. It has the capacity to extract 20.09kg/hr starch. Highest starch recovery was recorded at Treatment C at 32.1% higher than the existing SSE, highest extraction rate at Treatment B at 44.26kg/hr and highest extraction rate at Treatment B with 96.3%.

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