ADVANCES IN AGRICULTURAL AND FOOD RESEARCH JOURNAL

HH PUBLISHER

Original Research Article

Effect of Moisture Content on the Angle of Repose and Coefficient of Kinetic Friction of Sago Trunk (*Metroxylon* spp.)

Wan Mohd Fariz Wan Azman[1,2], Rosnah Shamsudin[1*], Mohd Zuhair Mohd Nor[1], Azman Hamzah [2]

[1]Department of Process and Food Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia,

[2]Engineering Research Central, MARDI Headquarters, Persiaran MARDI-UPM, 43400, Serdang, Selangor, Malaysia.

*Corresponding author: Rosnah Shamsudin; Department of Process and Food Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia; rosnahs@upm.edu.my

Abstract: Starch is one of the food sources extracted from cereals, roots, tubers, and stems. Sago palm (*Metroxylon spp.)* is one example of a starch source. The efficiency of the starch extraction process depends on the mechanical properties of the process material. A study was conducted to determine the angle of repose between the grated sago and the coefficient of kinetic friction between the sago trunk and stainless steel surface. The angle of repose (θ) of the 100 g grated sago was determined using the free flow method. The coefficient of kinetic friction between the sago trunk and stainless steel surface was determined using the pulling method at a speed of 1.27 mm/min, connected to force gauges. Both assessments were repeated at the different moisture content (MC) of 60%, 50%, 40%, and 30% of sago trunk. Based on the experimental results, the angle of repose (AoR= 47.00^0±0.31) and coefficient of kinetic friction (μ_k) 0.88±0.005 at MC= 60% showed decrease in value (AoR= 43.61^0±0.34; μ_k = 0.83±0.002) when the MC decrease to 30% (*p<0.01)*.

Keywords: sago trunk; grated; repose angle; coefficient of kinetic friction

Received: 3rd June 2020

Received in Revised Form: 2nd December 2020

Accepted: 10th December 2020

Available Online: 12th January 2021

Citation: Wan Azman WA, Shamsudin R, Mohd Nor MZ, *et al.* Effect of moisture content on the angle of repose and coefficient of kinetic friction of sago trunk (*Metroxylon* spp.). *Adv Agri Food Res J* 2021; 2(1): a0000179. https://doi.org/10.36877/aafrj.a0000179

1. Introduction

According to Yamamoto (2014), sago palms store a large amount of starch between the fiber gap, and it has four times higher starch content than rice. Therefore, it is a high potential to be used in the manufacturing and food industries. The sago industry in Malaysia, especially the state of Sarawak, was well established, contributing to export state revenue (Kamal *et al*., 2007; Karim *et al*., 2008). This is because the state has a large swampy area suitable for the cultivation of sago palm and the ideal environment for sago palm to grow naturally. Furthermore, the total output of sago starch production in Malaysia recorded about 184,163 metric tons in 2015 (DOA, 2015) and increased to 212,447 metric tons in 2017 (DOA, 2017) with RM 424 million.

In current sago processing practice, usually, the sago trunk's bark was peeled and split into a small piece before grating. Then the trunk was placed on a feeding platform and fed toward the grater blade either manually or using a mechanical system. Kinetic friction between the sago trunk and the surface of the feeding platform takes place during this process. Using a grating machine which is operated by a diesel engine, the sago trunk will be grated. Usually, the grater blade was built from a disc board or roller and attached with a sharp spike. The grated sago produce will accumulate inside the holding tank and form a pile of grated sago. Then, it slowly slides down to the drain path—the grated trunks mixed with water and transferred to a screener for the extraction process. The extracted solution was channeled to a collecting tank for the sedimentation process. The sedimentation process takes about 2 hours to settle down all the floating native sago starch at the bottom of the tank. Finally, the collection of wet starch was drying at an open space area (Cecil, 2002; Oates *et al*., 2002; Darma *et al*., 2017). The handling of the entire process still involves a high number of manual handling with minimal usage of machine tools.

Friction is a resistance force related to the motion of solid surfaces, fluid layers, and material elements sliding against each other. Static friction is the threshold force that must be overcome before a solid can slide over another. When the two materials are on top of each other, the load is locked together into local minimum energy, know as static friction (F_s). A force of kinetic friction (F_k) is needed to break the static friction energy to free them from sliding over one another. (Robbins & Müser, 2000). Since the load force affects the weight of the material and the gravity force that acts on the surface area, thus the coefficient of friction is defined as the ratio of the friction force to the normal force ($\mu_k = F/N$). In order words, the coefficient of friction (μ) is a force that resists one body's motion concerning another body in contact with it.

The inclination angle of the free surface to the horizontal of a bulk solid pile is also known as the angle of repose (AoR). It is a primary property to indicate the inter particulate friction. It is used to characterize the granular materials or powder's behavior concerning flowability (Zhou *et al*., 2002), avalanching (Frette *et al*., 1996), and stratification (Baxter *et al*., 1998). Based on previous studies, a factor affecting the angle of repose is the presence of water or the moisture content percentage (MC%) of material, which should be considered. It was reported that the angle of repose increased nonlinearly with the increase in MC% (Train, 1958). The angle of repose is essential for the design of processing, storage, and conveying systems of particulate materials.

For this study, a design parameter is the angle of repose of the grated sago, and the coefficient of kinetic friction between the sago trunk and stainless steel was studied. All the information obtained will be used as a guide for designing new machines for the following study to minimize manual operation.

2. Materials and Methods

2.1. Sago Trunk Preparation

The sago palm was obtained from the Labu area (State of Negeri Sembilan) and transported to the testing lab at MARDI, Serdang. The sago trunk outer layers (bark) were peeled off and cut into square blocks of 8 cm × 8 cm × 8 cm using handheld chainsaws (OG6816, Ogawa, Japan), and 24 blocks were provided for sampling. An initial moisture content percentage (MC%) of the sago trunk's sample was collected. The blocks were divided into four groups (G1, G2, G3, and G4), six blocks per group. Next, a different sago block was provided for a second assessment and grated using a roller grater (Roller Grater, MARDI). 4 kg of grated sago was collected and divided into four groups (G5, G6, G7, and G8) which is 1 kg per groups.

A pair of the group between sago blocks and grated sago (G2 and G6, G3 and G7, G4 and G8), which is at an initial moisture content of 60%, were dried until they reach the requirement of moisture content of 50%, 40% and 30% respectively (Table 1), the pair of group G1 and G5 was set as a control (initial MC%≈ 60%). The dying process was conducted using a drying oven (FAC-100, Protech, Malaysia). The drying temperature was set at 68ºC (Jong, 1995). During the drying process, the sample's moisture content was taken every 30 minutes until the readings reach the requirement of moisture content. The moisture test was conducted using laboratory equipment (HE53 230V, Mettler Toledo, USA).

Table 1. A pair of the group at the different requirement of moisture content

Groups	Moisture content
G1 and G5	60%
G2 and G6	50%
G3 and G7	40%
G4 and G8	30%

2.2. Coefficient of Kinetic Friction

A square block of sago trunk was placed on a stainless steel plate (Table 2) and attached with a rope at the middle position of the side surface to prevent from tipping effect. A hook was mounted at the end of the ropes and attached to force gauges (5567 Series Load Frame, INSTRON, USA), as visualized in the schematic diagram (Figure 1). The pulling speed (1.27 mm/min) and the test followed the standard of ASTM D2394 (Totten, 1992). The total pulling load (F) was recorded. The test was repeated with a different sago block (G1, G2, G3, and G4). To eliminate measurement error, each test was repeated six times for the mean value.

In general, the sago block tends to move in the pulling direction because of the pulling load (F). However, the load (F) was resisted by the friction force (F_k), resulting in between the sago block and stainless steel plate. Furthermore, when the pulling load (F) was more significant than the friction force, the sago block will slide to the puling direction at a constant velocity. Therefore the equation of coefficient of kinetic friction (μ_k) was:

$$F_k = F$$
$$\mu_k wg = F$$
$$\mu_k = \frac{F}{wg} \quad (1)$$

Razzaq *et al*. (2019)

Where:
F = pulling load (N)
F_k = friction force (N)
μ_k =Coefficient of kinetic friction
w = weight load (kg)
g = gravity acceleration 9.81 m/s^2

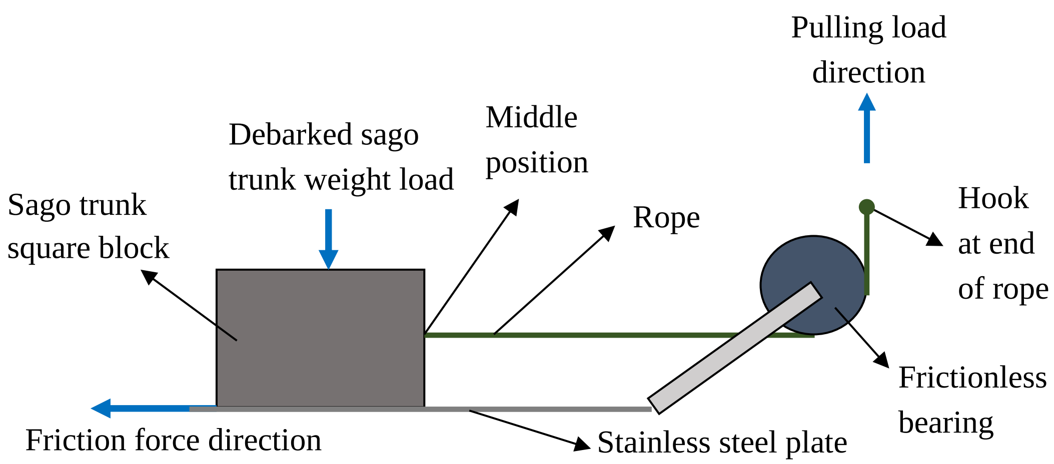

Figure 1. Schematic diagram of kinetic friction coefficient test

Table 2. The surface roughness of the AISI 304 stainless steel properties (Mirjam *et al*., 2014)

Material	$\mathbf{R_p}$**,µm**	$\mathbf{R_a}$**,µm**
AISI 304 stainless steel	0.37	0.16

2.3. Assessment of Grated Sago Size Distribution

To separate the grated sago particles according to scale, the sieving process was carried out at sizes of 2.80 mm, 2.00 mm, 1.00 mm, 0.85 mm, 0.45 mm, and 0.30 mm (Wan Mohd Fariz *et al*., 2020). First, the grated sago was dried at 68°C (Jong, 1995) using an air-drying oven (FAC-100, Protech, Malaysia). When the moisture content (MC%) value displayed a constant value for three consecutive readings taken every half an hour, the drying process was stopped. The dried grated sago (100 g) sieving process was then carried out using a sieve shaker (Endecott, United Kingdom). The sieving process was stopped when three consecutive readings (every 10-minute interval) of the total weight showed a constant value (ASTM, 2001). The process was repeated six times, and an average (µ) was recorded. Finally, the Weight Percentage Ratios (WPR) were determined (equation 2).

$$\text{Weight Percentage Ratio (WPR)\%} = \frac{\text{Weight of the sieved products}}{\text{Total weight of grated sago sample}} \times 100\% \qquad (2)$$

2.4. Grated Sago Angle of Repose

The angle of repose (θ) of grated sago was determined by using a cone-shaped hopper with an opening of 15 cm diameter, end closing 2 cm diameter, and height of 15 cm. The cone was attached to an adjustable height bar (up and down moving direction). A 10 cm diameter of a cylinder with 2 cm height was placed on the bottom surface (Figure 2) as a cup to hold grated sago. The cone was filled with a 100 g sample of grated sago and slowly adjusted the cone position in the upward direction to release the grated sago. After all the grated sago was released, it will form a conical shape. The grated sago cone shape base diameter (d = 10 cm) and height (h) were measured. The angle of repose was calculated using Equation 1. A similar procedure for the angle of repose test was performed by Cheng (2018). To eliminate measurement error, each test was repeated six times for the mean value.

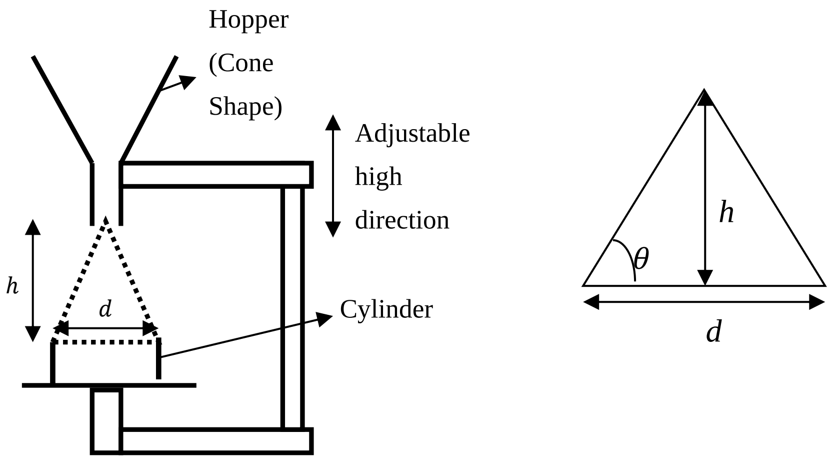

Figure 2. Schematic diagram of repose angle measurement equipment

$$\theta = \tan^{-1}\frac{2h}{d} \qquad \text{(Cheng, 2018)} \qquad (3)$$

Where θ is the angle of repose (degree), d is the cone shape base diameter (cm), h is the cone shape height (cm).

2.3. Statistic Analysis

All statistical data analysis is calculated using IBM SPSS Statistics 25.0 software to determine the average value (μ), standard deviation (±), *p*-value, and one-way analysis of variance (ANOVA).

3. Results and discussion

3.1 The Initial Moisture Content of Sago Trunk

Table 3 shows the average, minimum and maximum value of the initial MC% of the sago trunk. The results show that the average sago trunk MC% approximately 59.60±4.47%. The MC% of the sago trunk from 51.23±1.72% to 60.01±1.31% based on the total reported data. In contrast, the MC% of sago trunk collected was lower than the palm oil trunk, which was 78%, 75%, and 67% (74.00±4.58% on average) (Yamada *et al*., 2010), and the percentage difference was 20.27% ($p<0.01$). Compared to ordinary wood timber, the MC% of sago trunk was extremely high, ranging between 40% to 50%, as Yamada et al. (2010) reported. Due to the high moisture content value, the water presence factor in the next section of the study is taken into account.

Table 3. The moisture content (MC%) of the sago trunk. Error bars were expressed as mean ± SD; n = 12

Average (%)	Minimum (%)	Maximum (%)
59.60±4.47	51.23±1.72	60.01±1.31

3.2. Coefficient of Kinetic Friction between Sago Trunk and Stainless Steel Plate

A study on the coefficient of kinetic friction was conducted to measure the required force to slide an object on a stainless steel surface related to friction force. It is helpful in the design of handling equipment and improving the production systems. In this case study, a friction force occurs between the sago log and the feeding platform during the feeding process of the sago trunk toward the grater blade. Furthermore, there is a probability that the sago trunk loses water content due to the delay of processing activity which is causing the moisture content percentage (MC) to decrease. The moisture content of wood or chip decreases significantly dependent on season, storage duration, assortment, and fleece cover (Nicolas *et al*., 2018).

Figure 3 shows the coefficient friction (Equation 1) between sago trunks at different moisture content with a stainless steel surface. The result shows that the coefficient friction between sago trunk and stainless steel at a moisture content of 60% (0.38±0.005) was the highest compare to others which is 0.87±0.002, 0.86±0.002, and 0.83±0.002 at 50%, 40%, and 30% of moisture content, respectively. The coefficient friction is directly proportional to the increase of moisture content with a correlation value R^2 = 0.9792 and a significant difference of $p<0.01$ (F-value= 14103.14), as shown in Table 4. This is because the coefficient friction increases with the increasing moisture content of the material, causing the surface to become sticky (Bagherpour *et al*., 2009) since it increased adhesive force on the contact surface (Balasubramanian & Viswanathan, 2010). Usually, water droplets have a spherical shape because a robust and cohesive force tends to unite the molecules of a liquid. When a liquid comes into contact with a surface, both cohesive and adhesive forces will act on it. However, the effects of adhesive forces between water and contact surface are more potent. The liquid tends to spread out on the surface material to form a thin layer, relatively uniform film over the surface, known as the wetting process. Because the adhesive forces between water and surface material are strong enough to pull the water molecules out of their spherical shape and hold them against the contact surface, creating a sticky surface. Further, as Shafaei and Kamgar (2017) reported, a study on static and dynamic friction coefficient between wheat grain and five differences of the contact surface showed the effect of moisture content on friction coefficient between material surface similar.

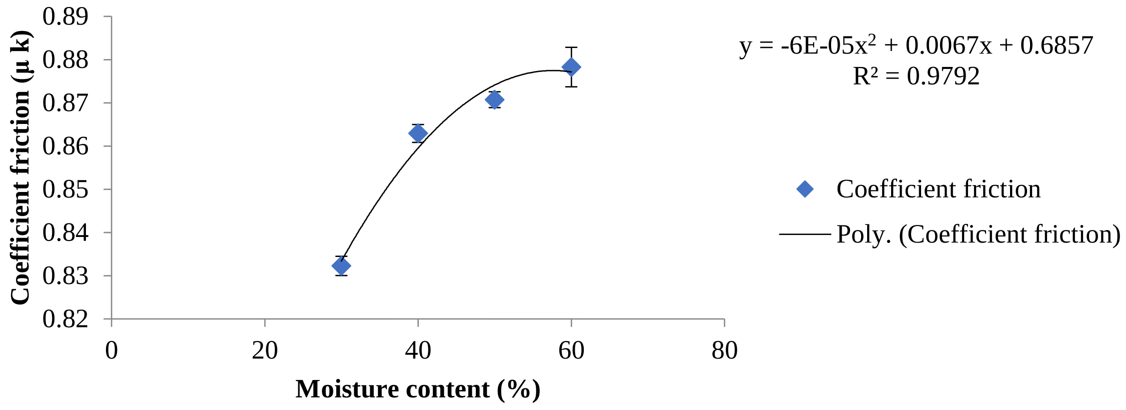

Figure 3. The coefficient friction force between sago trunk and stainless steel at different moisture content. The data value was expressed as mean ± SD; n = 20.

Table 4. Summary of one-way analysis of variance (ANOVA) for coefficient friction mean.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.47	3	0.16	14103.14	1.2E-189	2.66

[2] Dependent Variable: Coefficient friction

The basic linear equation (4) has been developed, showing the correlation between coefficient friction and material moisture content. The lowest moisture content after the drying process on average was 5.53±0.44% (Wan Mohd Fariz *et al*., 2018). Therefore the lowest value of coefficient friction of sago trunk at dry condition (5.53±0.44%) was predicted approximately 0.80, which is the minimum coefficient friction that needs to be addressed for the feeding mechanism.

$$\mu_k = 0.0015(MC) + 0.7954 \quad (4)$$

3.3. Size Distribution of Grated Sago and Angle of Repose at Different Moisture Content

Before the grated sago angle of repose was determined, an assessment of the grated sago size was carried out to specify the size distribution since the size distribution depends on the type of machine used as reported by Wan Mohd Fariz *et al*. (2018), which significantly affects the angle of repose value (Beakawi Al-Hashemi & Baghabra Al-Amoudi, 2018). The assessment of grated sago size distribution was performed at a moisture content of 3.53±1.76%. Figure 4 shows the WPR (%) of grated sago at different grated sago size distribution. The bar graphs display the same WPR% pattern distribution as recorded by Wan Mohd Fariz *et al*. (2018), a high concentration distribution in the range of 29.80 to 30.46%

at mesh sizes of 45 ≤ X< 0.85 and 1.00 ≤ X< 2.00. The WPR% does not surpass ≤10.26% for other mesh sizes.

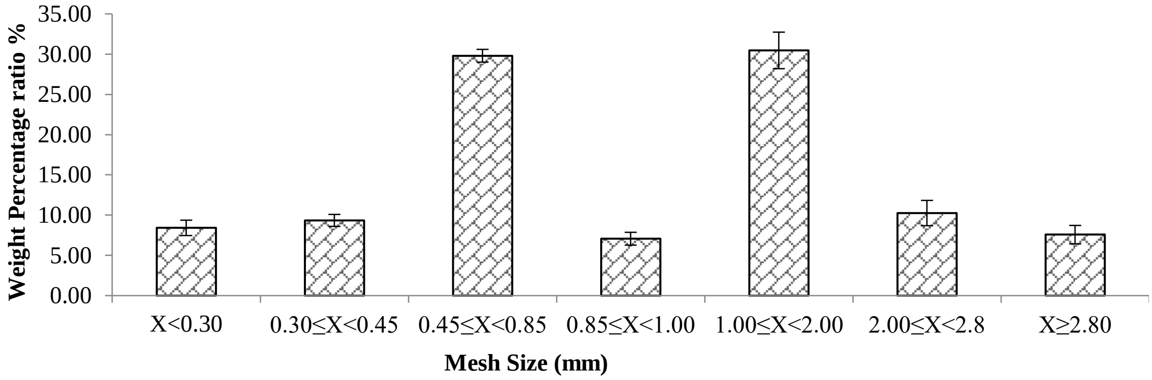

Figure 4. The grated sago size distribution on WPR (%) of Roller grater. Error bars were expressed as mean ± SD; *n* = 6

The angle of repose measures the angle of inclination of the solid pile. Identifying the inclination angle allows the pile material to move and slide freely on top of each other. In this case, a solid pile of sago trunk occurs during the grating process and accumulated inside the holding tank. It is essential to study the angle of repose to avoid the grated sago getting clogged and flow smoothly during processing activity. Figure 5 shows the grated sago angle of repose (Equation 3) at different moisture content. The angle of repose is directly proportional to the increase of moisture content with a correlation value of R^2 = 0.9996 and with a significant difference of $p<0.01$ (F-value= 59.45), as shown in Table 5. The result agrees with Kanawade *et al*. (1990), who conducted a study on the effects of moisture content on the repose of pigeon pea, chickpea, cowpea, green gram, black gram, soybean, and moth bean seeds. Their study showed that the higher the moisture content, the larger the angle of repose. This is because the coefficient of static friction increases between grated sago with increasing moisture content (Balasubramanian & Viswanathan, 2010).

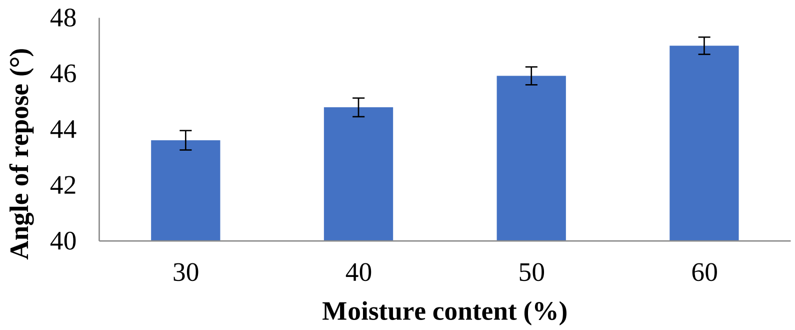

Figure 5. The grated sago angle of repose at different moisture content. Error bars were expressed as mean ± SD; *n* = 6.

A high angle of repose (47.00^0±0.31) occurred at the highest of moisture content (60%) and followed by 50% (45.92^0±0.31), 40% (44.79^0±0.33), and 30% (43.61^0±0.35). Beakawi Al-Hashemi and Baghabra Al-Amoudi (2018) reported that a bulk material that has a hard shell such as a seed has freely capable of flowing and usually has an angle of repose less than 30^0. In contrast, materials with a higher angle of repose greater than 55^0 have sticky and caking properties. Again, the effects of adhesive force as discussed in the Coefficient of the kinetic friction results indicate that the presence of water content affects the mechanical properties of the material, which tends to increase the adhesive force between water and contact surface. The adhesive force between water and contact surface was acting to prevent the pile material from sliding on top of each other.

In order to avoid the grated sago getting clogged and flow smoothly inside the holding tank, the sliding angle of the holding tank design must be greater than 47.00^0 by taking into account the maximum value of sago trunk MC% (60.01±1.31%).

Table 5. Summary of one-way analysis of variance (ANOVA) for the angle of repose mean

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	19.19	3	6.40	59.45	8.21347E-06	4.07

[3]Dependent Variable: Extracted starch weight

4. Conclusions

The results show that the presence of water content influences the sago mechanical properties of coefficient friction and angle of repose. The coefficient friction and angle of repose value are directly proportional to the increase of moisture content (p<0.01). The highest value angle of repose (47.00^0±0.31) and coefficient of kinetic friction (0.88±0.005) was recorded occurred at 60% of moisture content, and the lowers value was 43.61^0±0.34 and 0.83±0.13 when the MC decrease to 30%. As a suggestion, the handling of the sago log during processing is preferable when the moisture content at a low percentage as it required low force energy to slide the log since the effect of coefficient friction is less. Meanwhile, the design of the holding tank sliding angle needs to be greater than 47.00^0 by taking into account the maximum value of sago trunk MC% (60.01±1.31%) in order to make sure the grated sago flow smoothly inside the holding tank.

Acknowledgments: The authors would like to acknowledge the financial support by MARDI (Project code: FS024210), CRAUN Research Sdn Bhd, and team members whose contribution to stimulating suggestions, encouragement, and coordinate this project.

Conflict of Interest: The authors declare no conflict of interest.

References

ASTM. (2001). Standard C136-01: Test method for sieve analysis of fine and coarse aggregates. ASTM International.

Bagherpour, H., Minaei, S. & Khoshtaghaza, M. H. (2009). Selected physico-mechanical properties of lentil seed. *International Agrophysics, 24*(1), 81–84

Balasubramanian, S. & Viswanathan, R., (2010). Influence of moisture content on physical properties of minor millets. *Journal of Food Science and Technology, 47*(3), 279–284. DOI: 10.1007/s13197-010-0043-z

Baxter, J., Tuzun, U., Heyes, D., *et al.* (1998). Stratification in poured granular heaps. *Nature, 391*, 136.

Beakawi Al-Hashemi, H. M. & Baghabra Al-Amoudi, O. S. (2018). A review on the angle of repose of granular materials. *Powder Technol, 330*, 397–417.

Cecil J. E. (2002). The development of technology for the extraction of sago. In K. Kainuma, M. Okazaki, Y. Toyoda & J. E. Cecil (Eds.), *Proceedings of the International Symposium on Sago (Sago 2001)* (pp. 83–91). Universal Academy Press.

Cheng, N. S. (2018). Angle of repose. In P. T. Bobrowsky & B. Marker (Eds.), *Encyclopedia of Engineering Geology* (pp. 23–25).Springer International Publishing.

Darma, Santos, B. & Reniana. (2017). Development of cylinder type sago rasping machine using pointed teeth. *International Journal of Engineering & Technology IJET-IJENS, 17*(1), 25–31.

DOA. (2015). Malaysia Industrial Crops Statistics. Department of Agriculture Malaysia.

DOA. (2017). Malaysia Industrial Crops Statistics. Department of Agriculture, Malaysia.

Frette, V., Christensen, K., Malthesorenssen, A., *et al.* (1996). Avalanche dynamics in pile of rice. *Nature, 379*, 49–52

Jong, F. S. (1995). Distribution and variation in the starch content of sago palms (*Metroxylon sagu rottb.)* at difference growth stages. *Sago Palm, 3,* 45–54.

Kamal, S. M. M., Mahmud, S. N., Hussain, S. A., *et al.* (2007). Improvement on sago flour processing. *International Journal of Engineering and Technology, 4(*1), 8–14.

Kanawade, L. R., Bhosale, B. W. & Kadam, M. S. (1990). Effects of moisture content on certain selected physical properties of pulse seeds. *Journal of Maharashtra Agricultural Universities, 15*(1), 60–62.

Karim, A. A., Pei-Lang Tie, Manan, D. M. A., *et al.* (2008). Starch from the sago (*Metroxylon sagu*) palm tree-properties, prospect, and challenges as a new industries source for food and other uses. *Comprehensive Reviews in Food Science and Food Safety, 7*, 215–228.

Mirjam, B. L., C'rt, M., Tadeja, K., *et al.* (2014). The effect of surface roughness on the corrosion properties of type AISI 304 stainless steel in diluted NaCl and urban rain solution. *Journal of Materials Engineering and Performance, 23*, 1695–1702.

Nicolas, H., Theresa, M., Fabian, S., *et al.* (2018). Drying effects and dry matter losses during seasonal storage of spruce wood chips under practical conditions. *Biomass and Bioenergy, 111*, 196–205

Oates, C.G. & Hicks, A. (2002). *Sago starch production in Asia and the Pacific; problems and prospects*. In: Kainuma K, Okazaki M, Toyoda Y, Cecil JE, editors. Proceedings of the International Symposium on Sago (2001). Tokyo, Japan: Universal Academy Press Inc., pp:27–36.

Razzaq, A. M., Majid, D. L., Ishak, M. R., *et al.* (2019). Effects of solid fly ash on wear behaviour of AA6063 aluminum alloy. *Reference Module in Materials Science and Materials Engineering*, 1–6. doi:10.1016/B978-0-12-803581-8.11582-6

Robbins, M. O. & Müser, M. H., (2000). Computer simulations of friction, lubrication, and wear. In B. Bhushan (Ed.), *Handbook of Modern Tribology* (pp.717–755). CRC Press.

Shafaei, S. M. & Kamgar, S. (2017). A comprehensive investigation on static and dynamic friction coefficients of wheat grain with the adoption of statistical analysis. *Journal of Advanced Research, 8*(4), 351–361

Totten, G. E. (Ed.). (1992). *ASM handbook, friction, lubrication, and wear technology* (18th ed.). ASM International.

Train, D. (1958). Some aspects of the property of angle of repose of powders. *Journal of Pharmacy and Pharmacology, 10*(S1), 127–135. https://doi.org/10.1111/j.2042-7158.1958.tb10391.x

Wan Mohd Fariz, W. A., Rosnah, S., Azman, H., *et al.* (2018). Effect of grater position on the size of grated sago (*Metroxylon* spp.). *Food Research, 2*(6), 572 – 577.

Wan Mohd Fariz, W. A., Rosnah, S., Mohd Zuhir, M. N., *et al.* (2020). The assessment of grated sago size produced by the different type of grating machine. *ASM Science Journal, 13*(4), 59–66.

Yamada, H., Tanaka, R., Sulaiman, O., *et al*. (2010). Old oil palm trunk: A promising source of sugars for bioethanol production. *Biomass and Bioenergy, 34*(11), 1608–1613.

Yamamoto (2014). Sago as an approach to food and nutritional security. The Global Food Security Forum, Kuala Lumpur.

Zhou, Y. C., Xu, B. H., Yu, A. B., *et al.* (2002). An experimental and numerical study of the angle of repose of coarse spheres. *Powder Technology, 125*(1), 45–54.