Design and performance testing of areca nut thresher machine using solid triangle spike tooth type

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Abstract. Technology for handling agricultural products from areca nut has received less attention. However, the economic potential of the areca nut is comparable to that of other palm trees. Threshing areca nut from the bunch is one of the procedures that must be completed to obtain high-quality betel nut. Therefore, this research aims to design and test an areca nut threshing machine that uses a solid triangle spike-type threshing tooth. This study uses an experimental manufacturing method in the workshop and laboratory testing. A detailed engineering drawing of areca nut thresher machine is a guide in carrying out the manufacturer. The influence of rotational speed on the threshing shaft (34 rpm, 42 rpm, and 50 rpm) was investigated to determine the machinery's performance (percentage of threshing results, engine capacity, and fuel consumption). This study indicates that the areca thresher machine has been successfully designed with a diesel motor driving source of 6.5 hp, 2200 rpm. Applied a rotational speed of 50 rpm will give the best percentage of threshing products. The increase in rotational speed applied to the threshing machine will be in line with the rise in the engine capacity. In addition, the fuel consumption of a diesel engine from this thresher machine is 0.039 l/hr.

1. Introduction

Areca nut (Areca catechu) is a type of monocotyledonous plant still included in the palm family. This plant is already quite widely known in Indonesian society due to its massive distribution. In Indonesia, areca nut plants can be found on the island of Sumatera (Aceh, North Sumatera, and West Sumatera), island of Sulawesi, and island of Kalimantan. Generally, the areca nut in Indonesia is cultivated as a land boundary marker plant with productivity that can reach 0.35 ton/ha. Unfortunately, high productivity of areca nut has not received serious attention when compared to other palms. For areca nut cultivation, mechanization technology from pre-harvest to post-harvest is still lagging other palm types.

In terms of advantages, areca nut has the main active ingredients in tannins and alkaloids, which are widely used in the pharmaceutical industry. Besides, many people in Indonesia use betel nut as an ingredient for consumption at certain traditional ceremonies. In addition, stems, midribs, fruit bunches, and fruit fibers can be used as the main ingredients in organic fertilizers.
Fresh areca nut must work through several procedures to obtain dried betel nut that is ready to use. The process stages that must be given at least start from harvesting the fruit on the tree, threshing, cutting, and drying. Harvesting areca nuts from the tree can be done using a knife attached to a stick of wood or bamboo. The fruit that has been harvested from the tree is still in the form of fruit bunches, so the threshing process must be carried out. The method of threshing bunches of areca nut by farmers is throwing the betel nut on a hard surface or pulling it one by one. In that approach, this method is ineffective because it takes a long time and can cause blisters on the hands of operators. Therefore, applied of mechanization for agriculture were important, as reported by Md Salleh, et al. [1], who designed the palm oil fruits harvester, Radzi, et al. [2] who developed harvesting and transportation machine in oil palm plantations, and Bulan, et al. [3] who designed the palm frond chopper.

Threshing machines for agricultural products have been widely known and developed. Among them are threshing machines for paddy [4-6], peanut [7], and soybeans [8-10]. However, to the best of our knowledge, no one has developed a thresher machine for areca nut until now. Therefore, this study aims to design and testing a betel nut threshing machine. The areca nut threshing machine was developed using a solid triangle spike tooth type.

2. Materials and Methods

2.1. Analysis of some physical properties of areca nut

The dimensions of the fresh areca nut bunches used in this study (Figure 1) were characterized by the average diameter and height of bunches. The average diameter of the bunches is calculated using Equation 1. The bulk density of the fresh areca nut is measured by placing the betel nut in a certain container with known volume and weight. Furthermore, bulk density can be calculated using Equation 2. The angle of repose is measured by pouring betel nut on a flat iron material surface so that the pile height and pile diameter were obtained. Furthermore, Equation 3 was used to compute the angle of repose.

$$D_r = \frac{L_1 + L_2 + L_3}{3}$$  \hspace{1cm} (1)

$$B_d = \frac{m}{V}$$  \hspace{1cm} (2)

$$\alpha = \tan^{-1} \left( \frac{2h}{d_t} \right)$$  \hspace{1cm} (3)

Where, $D_r$-average diameter of fresh areca nut bunches (mm), $L_1$-side length of section 1 from the bunch (mm), $L_2$-side length of section 2 from the bunch (mm), $L_3$-side length of section 3 from the bunch (mm), $B_d$-bulk density (g/cm$^3$), $m$-betel nut mass (g), $V$-container volume (cm$^3$), $\alpha$-angle of repose (°), $h$-grain pile height (mm), $d_t$-pile average diameter (mm).

The force required to remove one fresh areca nut from the bunch was measured using a tensile scale (0.1 g), as shown in Figure 2. The measurement was repeated five times.
2.2. Mechanical analysis

The mechanical analysis of the areca nut thresher machine that will be designed consists of determining the angular speed of the threshing shaft (Equation 4), threshing torque (Equation 5), and calculate the total engine power requirement (Equation 6). It is assumed that the thresher tooth will thresh 16 betel nuts at the same time. This is because there have four threshing blade gaps on the four threshing blades working simultaneously in one threshing shaft.

\[ \omega = \frac{2 \cdot \pi \cdot n}{60} \]  
\[ T = F \cdot r \cdot n_b \]  
\[ P = \frac{T \times \omega}{\eta} \]  

Where; \( \omega \)-angular speed (rad/s), \( \pi \)-3.14, \( n \)-rotational speed (rpm), \( T \)-torsion (N.m), \( F \)-pull force to thresh betel nuts, \( r \)-threshing arm (m), \( n_b \)-number of betel nuts that are threshed at the same time, \( P \)-power requirement (watt), \( \eta \)-engine efficiency (%).

The minimum engine power requirement was carried out at the maximum rotational speed of the threshing shaft (50 rpm), and the maximum of threshed betel nuts was 16. This condition will require a force of 957.46 N to thresh 16 betel nuts at the same time. The radius of the threshing arm is designed to measure 245 mm. The diesel engine efficiency was about 75%. From this assumption, the torque required to thresh the betel nut was 191.5 N.m, so that the minimum total power needed for the areca thresher machine was 1636.82 watts (2.20 hp).

2.3. Machine testing

Machine testing was carried out at three threshing shaft rotational speed levels: 34 rpm, 42 rpm, and 50 rpm. This speed level is selected based on several rotational speed references of several threshing machines for agricultural products [11]. In addition, fuel consumption is also measured by comparing the fuel volume used during the threshing machine with the threshing time.

The initial weight of the fresh areca nut bunches is weighed before threshing. After threshing, areca nut and only bunches are re-weighed. Based on this mass, the parameter of the percentage of betel nuts that can be threshed can be calculated using Equation 7. In addition, the percentage of areca nuts that are un-threshed can be calculated using Equation 8. Furthermore, the percentage of heavy losses due to this threshing machine can be calculated using Equation 9.

\[ P_t = \frac{W_{TAT}}{W_{HT}} \times 100\% \]  

Figure 2. Schematic diagram of the single threshing force test of fresh areca nut.
\[ P_{UT} = \frac{W_{BAT}}{W_{BT}} \times 100\% \quad (8) \]

\[ L = \frac{W_{BT} - W_{FAT} - W_{BAT}}{W_{BT}} \times 100\% \quad (9) \]

Where; \( P_T \)-threshing betel nut percentage (%), \( W_{FAT} \)-weight of betel nut after threshing (g), \( W_{BT} \)-weight of betel nut and its bunch before threshing (g), \( P_{UT} \)-un-threshing betel nut percentage (%), \( W_{BAT} \)-weight of betel nut and its bunch after threshing (g), \( L \)-losses percentage (%).

3. Results and Discussion

3.1. Machine description

The design of areca nut thresher machine with solid triangle spike tooth type can be seen in Figure 3. This machine's length, width, and height are 2200 mm, 700 mm, 1060 mm, respectively. The total weight of this machine was 167 kg. The number of the threshing tooth used was 4, where each threshing tooth has four slits. The total diameter of the threshing unit is 490 mm, which was attached to a graded shaft with diameters of 100 mm and 30 mm, respectively. The total length of the threshing shaft was 1180 mm.

![Diagram of areca nut thresher machine](image)

**Figure 3.** (a) Design of fresh areca nut threshing machine (b) solid triangle spike tooth type, (c) threshing machine testing.

The blade on the thresher machine was in the form of a solid triangle spike tooth type made of UNP type iron plate with a thickness of 3 mm, a length of 150 mm, and a width of 60 mm. The threshing tooth was connected to the main shaft with a diameter of 100 mm with a shaft sleeve of 40 mm in diameter and 195 mm in length. The process of connecting all the parts using welding techniques.

The engine frame was designed using UNP iron 50 mm \( \times \) 30 mm. Meanwhile, the hopper was made of an iron plate with a thickness of 2 mm, and the UNP type is 50 mm30 mm. The hopper has a length, width, and height of 480 mm, 700 mm, and 140 mm, respectively. The designed hopper slope was about 33°. The tilt angle of this hopper is greater than the angle of repose of the areca nut, which was 23.58±2.94°.

The driving source was RD 65 DI-S diesel engine with maximum power and rotational speed of 6.5 hp, 2200 rpm, respectively. Threshing machine power was 2.95 times greater than the analysis of the need for driving resources. Power transmission system used from the engine to the threshing shaft was a V-belt-pulley. Variation of rotational speed on the threshing shaft (34 rpm, 42 rpm, and 50 rpm) achieves by adjusts the engine rotation speed lever [12, 13]. This arm can be adjusted so that the rotation speed on the engine was 800 rpm, 1000 rpm, and 1200 rpm, respectively. In addition, a reducer with a capacity of 1:10 was used to reduce rotational speed during transmission from drive source to the threshing shaft.
3.2. Characteristics of betel nut samples
The betel nut bunches tested in this study had an average diameter and height of 658.3±52.04 mm, and 483.3±230.9 mm, respectively. Areca nut has a bulk density and angle of repose of 0.44±0.005 g/cm$^3$, 23.58±2.94°, respectively. Based on preliminary testing, it can be seen that the force required to thresh one betel nut from the bunch is 59.84±11.19 N.

3.3. Threshing percentage
The results of the threshing machine performance on the percentage of betel nut that can be threshed and un-threshed were presented in Figure 4. The percentage of threshing areca nut was directly proportional to the increase in rotational speed applied to the threshing shaft. Increasing the rotational speed of the threshing shaft by 47% will increase the percentage of areca nuts that can be threshed by 20.5% and reduce the percentage of un-threshed by 65.8%. This may be because the higher rotational speed will cause a greater momentum force between the betel nut and the threshing tooth. The greater the momentum force will have, the more significant effect of threshing the betel nut from the bunch.

3.4. Percentage of losses
The success rate in threshing areca nut as shown in the percentage of fruit that can be threshed; the percentage of yield loss during the threshing process was also analyzed, as in Figure 5. It can be seen that increasing the rotational speed of the threshing shaft will decrease the percentage of yield loss. However, at rotational speeds of 42 rpm and 50 rpm, there was no significant difference in yield loss. This yield loss was caused by part of the betel nut or betel nut bunches being wasted. This loss of weight can be generated, among others, by the evaporation of the moisture content of the betel nut during the threshing process and the presence of part of the betel nut or betel bunch left on the thresher blade.

3.5. Machine capacity and fuel consumption
The thresher machine capacity was analyzed and presented in Figure 6. It can be seen that the designed machine has a minimum and maximum capacity of 94.10 kg/hr and 108.14 kg/hr, respectively. The increase in the capacity of the threshing machine was proportional to the increase in the rotational speed of the threshing shaft. Threshing machine capacity increased by 14.9%, with an increase in rotational speed by 47%. In addition, it can also be seen that the level of fuel consumption when threshing was about 0.039 l/hr. Increasing the capacity of the threshing machine by increasing the rotational speed of the threshing shaft was thought to be caused by a shorter threshing time when using a higher speed.
Figure 5. Losses from threshing using an areca nut thresher machine.

Figure 6. Areca nut thresher machine capacity.

4. Conclusions
An areca nut thresher using solid triangle spike tooth type has been designed and tested for its performance. The areca nut thresher uses a diesel motor as a driving force and has a maximum rotational speed of 6.5 hp, 2200 rpm, respectively. The threshing machine has a total length, width, and height of 2200 mm, 700 mm, 1060 mm, respectively. The total weight of this machine is 167 kg. Last but not least, the threshing machine has worked according to its function with a maximum capacity of 108.14 kg/hr. The maximum percentage of fruit that can be knocked down was about 82%, with a minimum yield loss of 2%. The consumption of diesel fuel from this engine was about 0.039 l/hr.

References
[1] S. Md Salleh, E. A. Rahim, I. H. Ghazali, K. Azmi, A. R. Jelani, M. F. Ismail, et al., "Hand-arm Vibration Analysis of Palm Oil Fruit Harvester Machine," in Applied Mechanics and Materials, 2013, pp. 621-625.
[2] M. K. F. M. Radzi, M. A. M. Bakri, and M. R. M. Khalid, "Development of a harvesting and transportation machine for oil palm plantations," Journal of the Saudi Society of Agricultural Sciences, vol. 19, pp. 365-373, 2020.
[3] R. Bulan, Safrizal, M. Yasar, Y. Nata, and A. Sitorus, "Design and construction of chopper machine AE02-type for oil palm frond," INMATEH - Agricultural Engineering, vol. 57, pp. 165-172, 2019.
[4] M. A. Adedeji, H. T. Masphalma, and W. R. Ibrahim, "Design and construction of motorized paddy rice thresher," in *1st International Conference on Biosciences Research*, 2015, p. 120.

[5] C. Huang, L. Duan, Q. Liu, and W. Yang, "Development of a whole-feeding and automatic rice thresher for single plant," *Mathematical and Computer Modelling*, vol. 58, pp. 684-690, 2013.

[6] J. Adri, B. Rahim, and N. Erizon, "Rice Thresher Machines in Handling System Alley Blow Rice in Post-Harvest," in *Journal of Physics: Conference Series*, 2020, p. 012028.

[7] M. Aboegela and K. Mourad, "Development a Locale Thresher Machine for Separating Peanut Crop," *Journal of Soil Sciences and Agricultural Engineering*, vol. 12, pp. 131-135, 2021.

[8] O. Adeyeye, E. Sadiku, T. Osholana, A. Reddy, A. Olayinka, A. Ndamase, et al., "Construction and evaluation of soybeans thresher," *African Journal of Agricultural Research*, vol. 14, pp. 921-927, 2019.

[9] W. Chansrakoo and S. Chuan-Udom, "Factors of operation affecting performance of a short axial-flow soybean threshing unit," *Engineering Journal*, vol. 22, pp. 109-120, 2018.

[10] C. Fan, R. Lian, Y. Yu, Y. Ren, Y. Duan, Z. Bin-Bin, et al., "Optimization design of a soybean thresher," *Soybean Science*, vol. 36, pp. 138-142, 2017.

[11] S. G. Jambhulkar, C. Handa, and E. K. Kapgate, "A review on design and development of coconut deshelling machine," 2019.

[12] Munawar A A, Yunus Y, Deviandi and Satriyo P 2020 Calibration models database of near infrared spectroscopy to predict agricultural soil fertility properties *Data Br.* **30**

[13] Helmi H, Munawar A A, Bakhtiar B and Zulfahmi Z 2021 Comparisons among soil tillage system and their impacts to the tested rice varieties on lowland rainfed alluvial in aceh jaya *Food Res.* **5** 173–8