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DEVELOPMENT OF BLADE-TYPE COCONUT DEHUSKING MACHINE FOR COPRA PRODUCTION IN THE PHILIPPINES

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ABSTRACT The Philippines is the second-largest coconut producer in the world. More than half of the country's annual coconut production is processed into copra. Coconut dehusking in the country is commonly done at the farm level using a simple tool such as the share of a moldboard plow and relies mainly on manual labor which can be quite tedious and hazardous. This study was conducted to develop a blade-type coconut dehusking machine for local copra production. The machine had a total dimension of 1275mm x 1370mm x 1665mm and powered by a 5.97kW diesel engine. The machine was tested and evaluated using newly harvested brown coconut that is small, medium, and large-sized with equatorial diameter means of 152mm, 182mm, and 211 mm, respectively. The performance parameters of the machine such as dehusking capacity, dehusking efficiency, and percent coconut damaged as affected by the coconut sizes (Factor A: small, medium, large) and the operating speed of the dehusking roller (Factor B: 50rpm, 75rpm, 100rpm) were analyzed using a factorial experiment in Completely Randomized Design (CRD). Comparison among means was done using Duncan's Multiple Range Test (DMRT) at a 5% level of significance. Results show that the highest dehusking capacities of 588 pcs/hr and 559 pcs/hr, and dehusking efficiencies of 99.57% and 99.51%, were obtained at 100 rpm and 75 rpm. On the other hand, the lowest dehusking capacity of 287pcs/hr and dehusking efficiency of 99.10% was obtained at 50rpm. Increasing the operating speed of dehusking roller from 50rpm to 75 or 100rpm resulted in a higher dehusking capacity and efficiency of the machine. However, results also show that operating the machine at dehusking roller speed of 100rpm and higher would generate higher percent coconut damaged during machine operation. Thus, operating the machine at 75rpm will give an average dehusking capacity of 559 pcs/hr and efficiency of 99.52% with an acceptable amount of percent coconut damaged, giving an increase of 311% in comparison to the manual coconut dehusking capacity of 180 pcs/hr.

Keywords: Coconut, coconut dehusker, dehusking, copra, copra processing, Philippines.

INTRODUCTION Coconut is abundantly grown in Indonesia, the Philippines, and India (FAO, 2013). In the Philippines, the production of a massive supply of coconut is year-round. Being the second-largest producer of coconut in the world, statistics show that the country has an average of 3.517 million hectares of coconut area or 26% of its total agricultural land area (PCA, 2016). In fact, 68 out of 81 provinces comprising of 1,195 municipalities are coconut areas with 329.9 million bearing trees producing an average of 14.902 billion nuts per year or an average yield of 45 nuts per tree per year (PCA, 2016).

More than half of the country's annual coconut production is processed locally into copra. Copra, the dried coconut meat, is the main source of coconut oil products. Coconut oil accounts for 85-95% of the country's total coconut exports by volume, and 80% by value. In 2017 alone, a total of 0.911 million metric tons of coconut oil from copra with a total value of US$1.436 Billion was exported by the country (PCA, 2016).

In the country, the majority of around 3.5 million coconut farmers who are directly dependent on the coconut industry, process their coconut produce into copra products. Traditionally, copra production involves a series of processes that begin with coconut harvesting to dehusking, splitting, drying, scooping, re-drying of the half-dried meat, bagging, and transport of copra products to the nearest buyer.

Coconut dehusking is one of the key operations relevant to copra production. After harvesting, the coconut must be dehusked first before it is subjected to splitting and other processes. Due to the unavailability of a mechanical device for this operation at the farm level, coconut farmers are forced to rely mainly on the manual method using an idle share of moldboard plow as a dehusking tool. Using this tool, the person doing the process has to hold the coconut in his hand and impale it onto the spike to penetrate deep into the shell. Then, pushes the coconut downward with a slight twist to loosen the husks. The procedure is repeated along the circumference of the coconut about 4 to 5 times before all the coconut husks are finally removed from the coconut shell. On average, an experienced and skilled laborer can dehusk 2 - 3 coconuts per min or around 960 to 1,440 nuts per 8hr per day (Pascua et al., 2018).

In the past decades, many attempts were made to develop a mechanical device for coconut dehusking. Different concepts and designs were proposed and fabricated. However, until now, coconut dehusking is still accomplished by a manual process at the farm level in most coconut growing areas in the country.

The general objective of the study was to develop a blade-type coconut dehusking machine for copra production in the Philippines. Specifically, the study aimed to (1) design and fabricate a mechanical device for farm-level coconut dehusking operation; and (2) evaluate the performance of the machine in terms of dehusking capacity, dehusking efficiency, and percent of coconut damaged.

This machine would be essential for the mechanization of the local coconut industry particularly to copra production in the countryside.

MATERIALS AND METHODS The flow process, as shown in Figure 1, was followed in the development of the blade-type coconut dehusking machine.

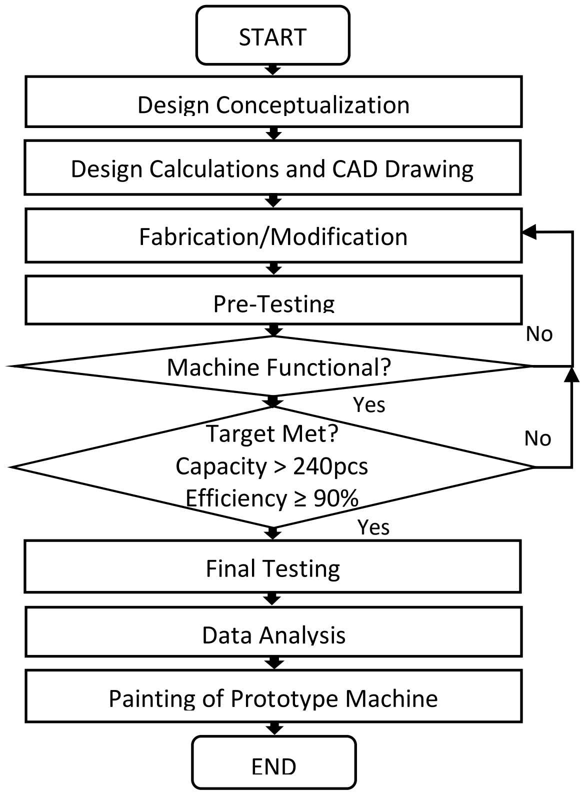

Figure 1. Flow process of developing the coconut dehusking machine

DESIGN CONCEPTUALIZATION AND CALCULATIONS The conceptualized design of the machine was compact that it could easily be moved from one location to another. In this design, coconut dehusking was performed in two stages: the first stage was removing the outer husk by the dehusking unit and the second stage was removing the remaining husks that were not removed by the dehusking unit. The basic design calculations, governed by the basic principles of machine design and approaches, were used to compute the necessary dimension requirements of each component of the machine.

Length of Dehusking Roller (L_{DR}) The length of dehusking roller was designed such that large coconut sizes were accommodated. The length of dehusking roller used in this study was 340mm. Equation 1 was used to determine the length of the dehusking roller.

$$L_{DR} = 1.10L_C \quad (1)$$

Where L_{DR} is the length of rollers (mm), and L_C is the maximum length of coconut (mm).

Number of Roller Blades (n) The number of the needed blades was determined using Equation 2.

$$n = \frac{\pi(D + 2h)}{w} \quad (2)$$

Where n is the number of blades, D is the diameter of the cylinder (mm), h is the height of blade (mm), and w is the width of coconut husk cut by one blade (mm).

Torque Required (T) The torque required to dehusk a large mature (brown) coconut was 480 N.m. It was determined using Equation 3.

$$T = Fr \tag{3}$$

Where T is the torque required (N.m), F is the maximum force (N), and r is the distance from the center of the shaft to the tip of the rollerblade (mm).

Power Required by Dehusking Roller (P_{DR}) The power required by the roller for dehusking was approximately 3.77 kW. It was computed using Equation 4.

$$P_{DR} = \frac{2\pi TN}{60,000} \tag{4}$$

Where: P_{DR} is the power available in the dehusking roller (kW), T is the torque required, (N.m), and N is the operating speed of the dehusking roller (rpm).

Power Required by Dehusking Unit (P_D) The power required to operate the dehusking unit was 4.15 kW. This was determined by adding 10% to the power available in the dehusking roller to run the belt conveyor as shown in Equation 5.

$$P_D = 1.10P_{DR} \tag{5}$$

Power Required by Cleaning Unit (P_C) The power required to operate the cleaning unit was approximately 1.5kW. This was approximately 35% of the power requirement of dehusking unit (Equation 6).

$$P_C = 0.35P_D \tag{6}$$

Total Power Required by the Machine (P_T) The total power required to operate the coconut dehusking machine was 5.95 kW. This was determined by adding the calculated power requirements of dehusking and cleaning unit as shown in Equation 7.

$$P_T = \frac{P_D + P_C}{e} \tag{7}$$

Where P_T is the total power required by the coconut dehusking machine (kW), P_D is the power required by the dehusking unit (kW), P_C is the power required by the cleaning unit (kW), and e is the overall transmission efficiency (95%).

Shaft Design The coconut dehusking machine involved various sizes of shafting. The standard shaft for agricultural machines with steel designation 1020 (cold rolled steel) and allowable shear stress of approximately 41.369 MPa (PAES 305:2000) was selected. The sizes of shafts subjected to the combination of torsion and bending were determined using Equation 8.

$$d = \left[\frac{16 \times 10^3}{\pi\tau}\sqrt{T^2 + M^2}\right]^{\frac{1}{3}} \quad (8)$$

Where d is the diameter of the shaft (mm), T is the maximum twisting moment (N-m), M is the maximum bending moment (N-m), and τ is the allowable shear stress (MPa).

Power Transmission System Design analysis on the power transmission system was carried out to allow proper sizing of the pulleys and sprockets to acquire desired speeds. The sizes of the pulley, belt, sprocket, chain, and gear were determined based on Philippine Agricultural Engineering Standards (2000).

Final Design of the Machine Based on the above concepts and calculations, the final design and detailed drawings of the coconut dehusking machine were generated using SOLIDWORKS 2016.

FABRICATION OF THE MACHINE The detailed drawings of the machine were used and followed during the fabrication. Locally available processes, equipment, and materials were used in the fabrication.

Technical Means for Ensuring Safety For safety reasons, guarding was provided for all belts and pulleys, chains, and sprockets following applicable standards set by the Philippine Agricultural Engineering Standard (2000). Moving components of the machine were generally treated as dangerous particularly the rollers and transmission systems. Thus, protective machine-like shields or covers were provided to guarantee the safety of operators.

Principles of Operation While the machine was running, each coconut was fed manually into the coconut dehusking unit in a horizontal position. During the dehusking process, each coconut was held between the rotating dehusking roller and running belt conveyor and pushed against the stationary counter bar. The two springs helped to adjust the clearance between the belt conveyor and dehusking roller according to the size of the coconut. As the dehusking roller rotated, the rollerblades penetrated the coconut husk and tore it away while the coconut was pushed by the roller to the counter bar, while one side of the belt conveyor was running in an upward direction which helped the coconut to twist during the process until all husks were removed from the shell of the coconut. The husk and partially dehusked coconut were then separated by the counter bar. When the coconut was already dehusked, the ejector lever located at the top cover of the dehusking unit was pulled at a certain angle to eject the coconut and to feed to the cleaning unit. Husks were discharged into the husk discharge chute. In the cleaning unit, as the rollers rotate, the rollerblades remove the remaining husk, particularly the crown portion of the coconut. The remaining husks were discharged in the husk discharge chute, while the dehusked coconut was conveyed by the screw conveyor to the coconut discharge chute to complete the process. Once the dehusking process was completed and the coconut is ejected, another coconut should be fed into the dehusking unit, and so on.

TESTING AND EVALUATION After fabrication and some necessary adjustments, the machine was subjected to final testing and evaluation. The machine was tested to assess its overall performance in terms of dehusking capacity, dehusking efficiency, and percent coconut damaged. All coconut samples were brown to ensure homogeneity in terms of maturity. The coconut samples with an equatorial diameter ranging from 126 – 165 mm, 166 – 205 mm, and 206 – 245 mm were classified into small, medium, and large, respectively. This range of measurement was decided based on the data provided by Philippine Coconut Authority (PCA). Two factors were considered: Factor A (coconut size) with three levels (A1, A2, A3), and Factor B (operating speed of dehusking roller) with three levels (B1, B2, B3). Three (3) replications were assigned to each of the nine treatment combinations. Randomization of the replicated treatment combinations was done to assign the sequence for each trial. Before the start of test trials, 5 pieces of coconut samples were randomly selected from every size-grouped to assign the number of samples per trial.

DETERMINATION OF PERFORMANCE PARAMETERS The performance of the machine was evaluated in terms of dehusking capacity, dehusking efficiency, and percent coconut damaged. Procedures and equations below were followed for the determination of these parameters.

Dehusking Capacity (DC) The dehusking capacity of the coconut dehusking machine was calculated by dividing the number of coconut samples dehusked by the total dehusking time multiplied by 3600, as shown in Equation 9.

$$DC = \frac{NS}{DT} \times 3600 \quad (9)$$

Where *DC* is the dehusking capacity of the machine (pcs/hr), *NS* is the number of the sample (pcs), and *DT* is the total dehusking time (s).

Dehusking Efficiency (DE) The dehusking efficiency of the machine was calculated by dividing the weight of the husk removed by the machine by the weight of the total husk multiplied by 100 percent, as shown in Equation 10.

$$DE = \frac{W_1}{W_1 + W_2} \times 100 \quad (10)$$

Where *DE* is the dehusking efficiency (%), W_1 is the weight of husk removed by the machine (g), and W_2 is the weight of un-removed husk (g).

%Coconut Damaged The percent coconut damaged was calculated by dividing the number of samples that incurred shell crack or breakage by the total number of samples multiplied by 100%, as shown in Equation 11.

$$\%Coconut\ Damaged = \frac{N_D}{N_T} \times 100 \quad (11)$$

Where N_D is the number of samples that incur crack or shell breakage (pcs), and N_T is the total number of samples (pcs).

Data Analysis Factorial in Completely Randomized Design (CRD) was used to analyze the effect of coconut sizes and the different levels of speeds of dehusking roller on the dehusking capacity, dehusking efficiency, and percent coconut damaged. The sources of variation are presented in standard ANOVA tables. Further, comparison among means was tested using Duncan's Multiple Range Test (DMRT) at a 5% level of significance.

RESULTS AND DISCUSSION The coconut dehusking machine was designed and developed to remove the husks from the coconut shell regardless of the size and husk thickness of the coconut.

DESCRIPTION OF THE MACHINE The blade-type coconut dehusking machine (Figure 2) was equipped with three integral parts, namely: dehusking unit, the cleaning unit, and the prime mover. The machine had a total dimension of 1275 mm x 1370 mm x 1665mm and a total weight with no engine of 240 kg. The entire assembly was painted to resist corrosion.

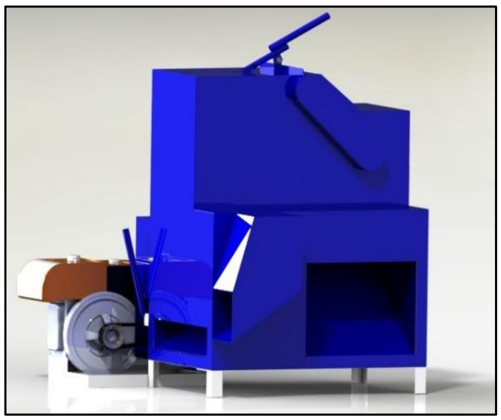

Figure 2. The Blade-type coconut dehusking machine.

Dehusking Unit The dehusking unit was considered the most important component of the machine because if it failed to do its intended function, other components would be useless. In this unit, the first stage of the dehusking process was carried out. The dehusking unit consisted of four main parts, namely; dehusking roller, counter bar, belt conveyor assembly, and ejector assembly. The dehusking roller was equipped with 21 pieces of blades welded equally around the circumferential area of the steel cylinder. The counter bar was placed stationary below the dehusking roller at a certain distance from the tip of the blades and a certain distance from the bottom part of the belt conveyor. It was employed to hold the coconut and allow it to twist while the dehusking roller and belt conveyor were running during the coconut dehusking operation. The belt conveyor assembly was placed in a vertical position at a certain distance from the dehusking roller. It was equipped with two springs attached at the bottom part of the support bars. The other ends of the springs were also attached to the frame of the machine. The ejector assembly was also employed in the dehusking unit to facilitate easy discharge of coconut to the cleaning unit after the first stage of the dehusking process.

Cleaning Unit The second stage of the dehusking process was done at the cleaning unit. In this unit, the remaining husks still attached to the coconut shell after the first stage of dehusking, particularly the crown of the coconut husk were removed. The cleaning unit was composed of three main parts, namely: cleaning rollers, screw conveyor, and side cover. Both cleaning rollers were placed such that the line joining the center of their shaft was parallel. Each roller was equipped with 32 pieces of blades. The screw conveyor was placed at a certain distance above one of the rollers to convey the coconut to the discharge chute. A side cover was provided to the cleaning unit to keep the coconut on the rotating rollers while the coconut was conveyed by the screw conveyor to the coconut discharge chute during the second stage of dehusking.

Prime Mover Fuel price was one of the considerations in the selection of prime mover. Since diesel fuel was cheaper than gasoline, a diesel engine was selected. Based on the calculated power requirement of the machine of 5.95 kW, the nearest available rated power for diesel engines available in the local market was 5.97kW. Thus, a diesel engine with a maximum power of 5.97kW was selected as a prime mover of the blade-type coconut dehusking machine.

MACHINE PERFORMANCE The overall performance of the machine was determined by measuring such parameters as dehusking capacity, dehusking efficiency, and percent of coconut damaged. Table 3 shows the summary of machine performance.

Dehusking Capacity The average dehusking capacity of the coconut dehusking machine as affected by coconut size and the operating speed of the dehusking roller is shown in Table 1. The highest dehusking capacity of 604 pcs/hr was obtained for medium coconut sizes at 100rpm. On the other hand, the lowest capacity (265 pcs/hr) was observed for small coconut sizes at 50 rpm operating speed of dehusking roller. Analysis of variance on the dehusking capacity of the machine as affected by coconut size and the operating speed of the dehusking roller reveals that the operating speed had a significant effect on the dehusking capacity of the machine. The coconut sizes and the interaction of the two factors, on the other hand, had no significant effect on the dehusking capacity of the machine. Comparison among means of the dehusking capacity as affected by the operating speed of the dehusking roller reveals that the dehusking capacities of 588pcs/hr and 559 pcs/hr at 100 rpm and 75 rpm, respectively, had no significant differences. Both, however, were significantly higher than the mean dehusking capacity of 287 pcs/hr at dehusking roller speed of 50 rpm.

Table 1. Average dehusking capacity (pcs/hr) as affected by coconut size and operating speed of dehusking roller

SPEED	COCONUT SIZE			MEAN
(rpm)	Small	Medium	Large	
50	265	297	298	287^b
75	574	557	545	559^a
100	589	604	572	588^a
MEAN	476	486	472	478

Means not sharing the same letter, in a row and a column, differ significantly by DMRT at a 5% level of significance

Increasing the operating speed of dehusking roller from 50 rpm to 75 or 100rpm resulted in a higher capacity of the coconut dehusking machine. Furthermore, the machine in this study recorded a higher dehusking capacity (559 to 588 pcs/hr) as compared to the 240 pcs/hr dehusking capacity of the mechanical coconut dehusker developed by Pascual et al. (2018).

Dehusking Efficiency The average dehusking efficiency of the coconut dehusking machine as affected by the coconut size and operating speed of the dehusking roller is shown in Table 2. Coconuts dehusked at 100rpm, 75rpm, and 50rpm had a dehusking efficiency means of 99.57%, 99.51%, and 99.10%, respectively. These results indicate that the higher the operating speed of the dehusking roller, the higher the dehusking efficiency of the machine. Analysis of variance on the dehusking efficiency reveals that dehusking efficiency was affected significantly by the size of the coconut and the operating speed of the dehusking roller. Comparison among means of the dehusking efficiency as affected by coconut size shows that the coconut dehusking machine tended to be more efficient in small and large-sized coconuts than in medium-sized coconuts. The mean dehusking efficiency for small (99.51%) and large-sized coconuts (99.49%) had no significant differences, but both were significantly different from that of the medium-sized coconuts (99.18%). Furthermore, comparison among means on the dehusking efficiency as affected by the operating speed of dehusking roller indicates that mean dehusking efficiencies of 99.57% and 99.51% for 100- and 75-rpm, respectively, had no significant differences. Comparing both to dehusking efficiency of 99.10% at 50rpm exhibited significant differences. This indicates that the machine performed better at either 100 or 75rpm of the dehusking roller. Moreover, the fabricated coconut dehusking machine also recorded a dehusking efficiency higher than 99% at the different operating speeds which were all higher when compared to the 85.23% dehusking efficiency of the mechanical coconut dehusker developed by Pascual et al. (2018).

Table 2. Average dehusking efficiency (%) as affected by coconut size and operating speed of dehusking roller.

SPEED (rpm)	COCONUT SIZE			MEAN
	Small	Medium	Large	
50	99.40	98.72	99.15	99.10[b]
75	99.60	99.28	99.65	99.51[a]
100	99.55	99.52	99.62	99.57[a]
MEAN	99.51[a]	99.18[b]	99.49[a]	99.39

Means not sharing the same letter, in a row and a column, differ significantly by DMRT at a 5% level of significance

Percent coconut damaged The result shows that the percent coconut damaged increased as the size of the coconut was increased. Similarly, operating the coconut dehusking machine at dehusking roller speed of 100rpm and higher would generate a higher percentage coconut damaged during machine operation.

SUMMARY OF MACHINE PERFORMANCE A total of 27 trials were done in this study. Table 3 below shows the summary of the performance of the blade-type coconut dehusking machine.

Table 3. Summary of machine performance.

Trial	Treatment Combination		Dehusking Capacity (pcs/hr)	Dehusking Efficiency (%)	Coconut Damaged (%)
	RPM	Coconut Size			
1	50	small	254	99.6	0
2	50	large	279	99.2	0
3	75	medium	594	98.7	20
4	100	large	593	99.4	40
5	100	large	562	99.7	20
6	75	small	573	99.7	0
7	100	large	560	99.8	60
8	50	large	306	99.2	0
9	100	small	542	99.6	20
10	75	small	583	99.5	0
11	75	large	527	99.6	0
12	75	medium	545	99.5	0
13	75	large	514	99.7	20
14	100	small	638	99.6	20
15	75	medium	532	99.6	0
16	50	small	261	99.1	0
17	50	small	279	99.5	0
18	50	medium	283	98.7	0
19	50	large	310	99.1	0
20	50	medium	321	99.1	0
21	75	small	566	99.6	0
22	75	large	595	99.7	0
23	100	medium	584	99.5	20
24	100	small	587	99.4	0
25	100	medium	665	99.6	40
26	50	medium	287	98.4	0
27	100	medium	564	99.5	20

CONCLUSION A blade-type coconut dehusking machine for copra production has been successfully designed and fabricated. Operating the machine at 75rpm will give an average dehusking capacity of 559 pcs/hr and efficiency of 99.52% with an acceptable amount of percent coconut damaged, giving an increase of 311% in comparison to the manual coconut dehusking capacity of 180 pcs/hr.

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