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Performance Characteristics of a Coconut Dehusking Machine

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Abstract

A coconut dehusking machine was developed and evaluated in terms of dehusking performance. The model consists of different component assembly parts such as speed reduction, transmission, coconut base, dehusking blade, frame, and control system. It is powered by a 7.5 hp gasoline engine and with an average output capacity of 240 coconut per hour. Its salient features which give it an edge over other existing machines in attaining effective dehusking are as follows: 1) a dehusking blade with cutting tooth and blade side face angle, 2) movable coconut base assembly, 3) ability to remove husks starting at the basal portion, which is the softest part of the coconut, and 4) operable by a single person. The cutting tooth initiates the initial penetration of the blades while the side face angle can assist better piercing or shearing action on the coconut husks. The coconut base can be moved upward or downward and can accommodate different coconut sizes. The effects of different factors which include the machine's crankshaft speed, coconut size, and blade side angle on the response variables were investigated. Response Surface Regression (RSReg) and Response Surface Methodology (RSM) were used to determine the effect of the treatment factors and optimum performance of the machine; respectively. Fifteen (15) experimental runs using Box and Behnken design with three level-incomplete factorial designs were conducted. The different dependent variables studied consisted of force and power requirement, dehusking time, dehusking capacity, percent coconut shell damage, and dehusking efficiency. Results revealed that variation on the levels of treatment factors significantly affect the response variables except percent coconut shell damage. Data obtained from the response variables mostly fit the linear, cross product, and quadratic regression models.
The superimposed contour plots of different factors generated an optimum region and yielded a dehusking performance with force requirement of 109.59 N, power consumption of 6.41kW, dehusking time of 3.34 minutes, dehusking rate of 4 nuts per minute and dehusking efficiency of 85.23 %. Moreover, results of the verification tests indicated that the actual values of responses were relatively close to the predicted values.

Keywords: Coconut, Dehusker, Force Transducer, Efficiency, Optimization

1. Introduction

Coconut (Cocos nucifera L.) is widely cultivated in tropical and sub-tropical countries. In the Philippines, statistics indicated that areas planted with coconut covers 3.517 M hectares equivalent to 26% of the total agricultural land (PSA, 2015). Sixty-eight (68) out of 81 provinces are considered coconut areas, representing 1,195 coconut municipalities. In 2015, the recorded number of bearing trees reached 329.9 million with an average production of 14.902 billion nuts in the last three years (PCA, 2017). Dar (2017) stated that the coconut lands host about 3.4 million farmers who are mostly below the poverty line even as coconut exports reached $2.0 billion in 2016.

Mechanization level of the coconut industry in the Philippines is still low (Amongo, et.al. 2011). Dehusking is first in the processing line of coconuts, has the lowest development in terms of machinery usage. According to Nijaguna (1988) as cited by Tanco (1998), coconut dehusking can be divided into 2 general operations namely:

piercing and peeling. Piercing consists of the largest force requirement ranging from 230 kg to 320 kg depending on the variety and maturity of the coconut fruit. On the other hand, peeling operation requires an average force of 40 kg, which involves removal of husk similar to the method used for peeling a banana fruit. Tanco (1998) stated useful requirements in order to achieve husk removal as follows: a) the penetrating tool must be able to enter the husk and reach the base end near the embryonic end of the outer shell and b) the tool should be able to peel the husk starting from the base end of the coconut towards the apical end.

Traditional methods of dehusking are still very popular at present besides being labor intensive. It is done either through the use of a sharp machete and a spike made of steel locally known as 'bolo' which involves cutting the stem and apical ends of the nut and making longitudinal cuts on the check and then levering the husk out using the tip end of the bolo. Manual dehusking is also done using a spike shaped tool locally known as "Lupasan". It could be a round bar with oblate, flat, and pointed end or spear-shaped metal tool. Many coconut farmers in the country make use of an idle share of a moldboard plow as dehusking device. The coconut (preferably the stem end side) is impaled onto the spike until it reaches the outer shell, and consequently pushing the nut downward with slight twist to loosen the fibers. Doing the same procedure for about 4 to 5 times before the husk fibers are finally removed from the nut. On the average, skilled workers can dehusk 3 nuts per minute or about 1,080 nuts at 6 hours shift per day using this method (based on actual observation). There were attempts to mechanize the husking operations in the country but it has not been perfected yet. Inventors have not been able to develop dehusking machines that are workable or functional in terms of completely removing coconut husk. Thus, invented machines had very low efficiency as well as dehusking time and capacity.

Mechanized coconut dehusking are mostly foreign made. Harries (1994) noted that machines for coconut dehusking have been developed since early 1930's in an attempt to imitate the traditional method but have failed due to the incapability of these machines to compete with the manual labor. Such machines were presented by Woodroof (1970) as cited by Tanco (1998). A pedal operated coconut dehusking machine was developed by Titmus and Hickish (1929) with a principle of impaling a nut on a pair of spikes initially together. After impaling, the foot pedal separates the spikes to remove the husks radially outwards. The process is repeated several times until most of the husks are removed.

Celaya (1930) made a hand operated dehusking machine with a supporting frame with hooks that held the coconut while it moves toward a set of knives positioned to slash the coconut. A hand operated dehusking tool was also developed by Waters (1949) that consisted of a pair of pivot handles with pointed teeth were forced through the coconut husk and then spread apart to open and separate the husk from the shell. A coconut dehusking machine was developed by Beeken (1959) in which coconut husk was removed by helical cut of a set of blades while the nut was held between jaws. A motor operated coconut dehusker developed by The Universtsity of New South Wales Australia as cited by Tanco (1998) has a principle of feeding the nuts on a conveyor belt into a system of contra-rotating rollers. The rollers have spiral flutes that remove the husk from the nut similar to a pencil sharpener. The shell is ejected and rolled between another set of rollers for final cleaning. The machine was claimed to have a capacity of about 1,000 nuts per hour.

A manual dehusking machine similar in principle to the design of Titmus and Hickish (1929) was adapted by Nijaguna (1988) as cited by Tanco (1998). It consisted of two sets of blades: one set has 3 blades arranged at 120˚ apart where the coconut is held where piercing takes place. Another set of blades moves radially outward to peel the husk. The machine works by pulling the lever to push the piercing blades through the husk and releasing the cam for the other set of blades that moves radially outward to effect peeling action. It was noted to have a capacity of 200 nuts per hour.

In India, labor cost for coconut dehusking is about 5 to 10% of the value of the nut. Mechanization and improvement of dehusking is a priority to lower the processing cost, thus allowing coconut products to compete in the market (Nijaguna, 1988). The machine designed by Jacob and Rajesh (2012) claimed a capacity of 120 to150 nuts per hour for large scale coconut plantations. The average time to dehusk a coconut is twenty five (25) seconds. The efficiency of the machine was not recorded in their study. The dehusking unit consists of two cylinders of different diameters with a clearance that is not adjustable. The two diameters provide different speeds at opposite directions causing a tearing effect on the husk.

Nwankwojike et.al. (2012) designed a coconut dehusking machine in Nigeria with a dehusking efficiency and capacity of 93.4% and 79 coconuts per hour, respectively. The dehusking unit is composed of two roller shafts and two spur gears. Metal spikes were welded on the rollers. A conveyor system in the form of a steel rod scrolled into one of the rollers is incorporated into the machine to facilitate movement of the coconut along the rollers while it is dehusked. The machine is powered manually by operating the hand crank fitted into one of the rollers.

The design specifications of foreign machines, however, may pose difficulties for small-scale shop manufacturing in the country. Foreign technology in most cases is functionally appropriate but does not meet the entire range of socio-economic conditions found in small scale manufacturing. The inappropriateness of foreign technologies had created the need to develop equipment and machines out of local materials, manufacturing technology, and manpower.

The lack of sufficient manpower necessitates the use of appropriate machinery to aid in various tasks in the aspects of coconut processing. Based on this realization, successful invention of a device that simplifies an important process as well as increases the productivity of the coconut industry is deemed necessary. The aim of this study is to attain the desired goals of increasing production output, lower possible power consumption and with higher capacity and efficiency.

2. Body of the Article

The machine (Figure 1) was designed based from the principle of traditional manual dehusking and the results from the study of Conge (1983) on some mechanical properties particularly the hardness, shearing and tensile resistances of coconut husk. The model is simple in terms of fabrication and made of locally available materials. The frame of the component parts were made detachable to facilitate ease of assembling and disassembling them together thus will give comfort during operation and transport. The component parts include the following: engine assembly, gearbox reducer assembly, dehusking machine assembly, and transmission system.

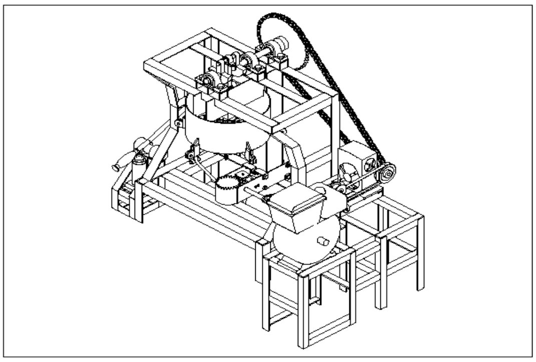

Figure 1. The isometric drawing of the coconut dehusking machine

The force requirement was determined by recording the measurement readings from the force sensor to the computer. The signal from the force sensor which is a very small stress value was received and amplified by the signal amplifier. The amplified signal was then digitized by the Arduino Software to be recognized by the computer. The digitized signal was further processed using Gobetwino Software for collection and recording of data thru the Asche file format. The software acts on behalf of Arduino and does some things that Arduino Software cannot do on its own. Data was then read by the computer using the notepad program.

The readings of signal (mV) start when the blade initially touches the sample and when at maximum downward stroke. Highest – lowest readings were recorded during operation per sample per treatment combination. The average force was determined using Equation 1:

$$\text{Ave. Force} = \left[\frac{\Sigma \text{ force readings}}{\text{no. of readings}}\right] \qquad \text{(Equation 1)}$$

The power consumed by the machine during dehusking operation was determined by multiplying the generated average force and the penetrating time of dehusking blades divided by the power conversion factor. The power consumed was calculated using Equation 2:

$$P = \frac{\text{Average Force}\left(\text{kg} - \frac{\text{m}}{s^2}\right) \text{x T}}{\text{cf}} \qquad \text{(Equation 2)}$$

Where: P = Power consumed (KW)
T = Penetration time (Sec.)
cf = Power conversion factor (1KW=102.0076kg-m/s)

The dehusking time (DT) was recorded in minutes using a stop watch. It was done by recording the time (in minutes) of coconut samples to attain complete dehusking per test run.

The percent damage was determined by recording the number of coconut fruits that incur shell crack or breakage out of the coconut samples.

The dehusking rate (DR) or dehusking capacity was the number of dehusked coconut fruit per unit time and it was computed using Equation 4:

$$DR = \frac{n}{DT} \qquad \text{(Equation 3)}$$

Where: DR = Dehusking rate (no. of coconut per minute)
n = Number of coconut samples
DT = Dehusking time (min.)

The dehusking efficiency was determined by measuring the weight of the removed as well as un-removed coconut husks. This was calculated by dividing the weight of the removed husk by the total weight of the husk multiplied by 100 percent (Equation 5).

$$DE = \left[\frac{W1}{W1 + W2}\right] \text{x } 100\% \qquad \text{(Equation 4)}$$

Where: DE = Dehusking efficiency (%)
W1 = Weight of removed husk (gms)
W2 = Weight of un-removed husk (gms)

All the data generated from the test runs were analyzed using the Response Surface Regression (PROC RSREG) which includes the analysis of variance (ANOVA), regression analysis, and calculations of regression coefficients. The Response Surface Methodology (RSM) was also used in this study to determine the optimum combination of the independent variables that would result in the optimum dehusking performance of the prototype machine. This was done to obtain an optimal response using a set of designed experiment in an approximated first degree polynomial model. According to Myers (1971), using RSM one can a) find a suitable approximating function for the purpose of predicting future response and b) determine what values of the independent variables is optimum as far as response is concerned. Moreover using the RSReg procedure, parameters of a complete quadratic response surface were fitted and critical values were also approximated. Three dimensional (3D) surface plots were also generated. The contour plots were superimposed to establish the optimum experimental region. Further, verification of the response models was conducted by separate test runs using derived optimum values. The results were compared with computed data using analysis of variance (ANOVA) subjected to 90% and 95% levels of confidence.

Performance of the Machine

The variation in dehusking force at different treatment variables showed that the highest recorded value was 122 N measured at 0° blade side angle for medium size coconut at both low and high operating blade speeds. The result was lower than 489.38 N maximum shearing force of coconut husk from the study of Peñaflor (2008) using Universal Testing Machine at crosshead speed of 106.48 mm-min^{-1} and coconut husk position of 144.33°. The result might be due to the position of the samples during the experiment wherein force was measured only at the basal portion which is the softest part of the coconut as stated by Conge (1983). On the other hand, the lowest average force of 80 N was gauged using 30° blade side angle for small and medium sizes of coconut fruits operating at high speed. This means that dehusking force was affected by the blade design particularly the blade side angle, crankshaft speed, and coconut size. Results show that as the blade side angle and crankshaft speed increases, the dehusking force decreases. Increase in dehusking force is also associated with the increase in coconut size. This might be attributed to the surface area penetrated by the dehusking blades with lower side angles as compared with those with higher side angles. This means that the higher surface area in contact between the dehusking blade and coconut husk the higher is the dehusking force. Higher surface area in contact might be due to the earlier time of contact of the side faces of the later on the coconut husk at smaller side face angles. Lesser force was also exhibited on larger sizes of coconut at faster rate.

It was observed that the highest power was about 7 kW using 0° blade side angle at medium operating speed. The lowest average power recorded was about 4 kW using 30° blade side angle for small and medium coconut sizes at high operating speeds. Furthermore, the power generated at the midrange was about 5.2 kW which was measured using 15° blade side angle tested on medium size coconut and operated at medium speed. Generally, power decreases as crankshaft speed and blade side angle increases (Fig. 3). Force of dehusking followed the same trend as power. However, increase on the size of coconut fruit was also associated with the increase in power requirement (Fig. 2). This suggests that larger coconut sizes will require a corresponding higher power output of the machine.

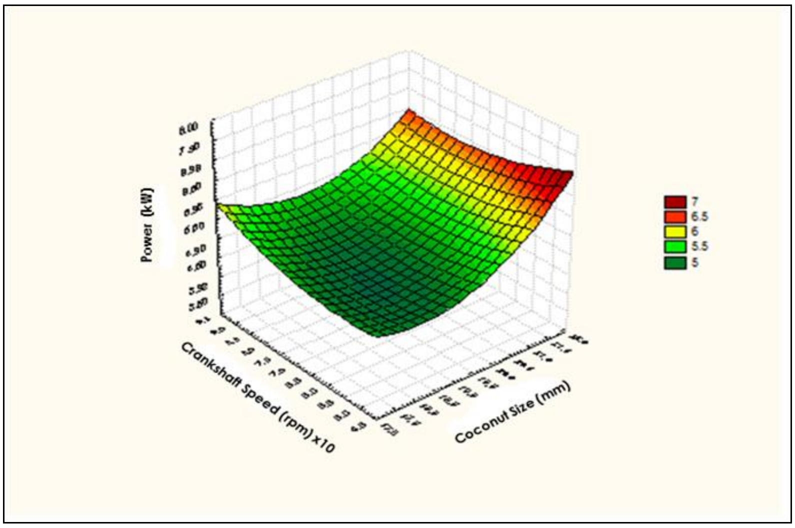

Figure 2. Variation in power as a function of crankshaft speed and coconut size

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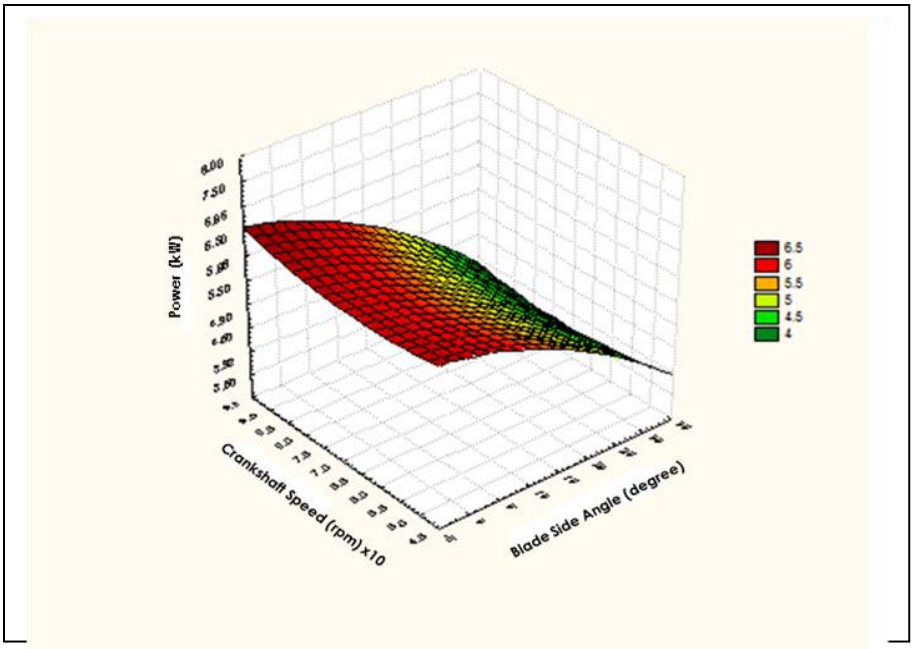

Figure 3. Variation in power as a function of crankshaft speed and blade side angle

The highest average dehusking time of 5.90 minutes was measured for both medium and large sizes of coconut and for blade side angles of 15º and 30º operated at a crankshaft speed of 50 rpm. On the other hand, lowest average time of dehusking was less than 3 minutes for medium size coconut, 15º blade side angle operated at 70 rpm. This means that dehusking time was greatly affected by crankshaft speed, blade side angle, and coconut size. Generally, dehusking time decreases with increasing coconut size but decreasing machine speed and blade side angle.

Dehusking capacity increases with increasing crankshaft speed and coconut size, and decreasing blade side angle. The highest average dehusking capacity was about 4 coconut fruits per minute using medium size coconut with 15º blade side angle at crankshaft speed of 70 rpm while the lowest average value was 1.70 coconut fruits per minute for both medium and large coconut fruits using15º and 30º blade side angles at speed of 50 rpm. This means that using blades with 15º side face angles can finish dehusking 40 coconut fruits with in an average of 10 minutes dehusking time at 70 rpm crankshaft speed. On the other hand, using blades with side angles of 30º can dehusk only about 20 coconut fruits within the same average dehusking time. Furthermore, values in capacity using dehusking blades with 15º side face angles are within the average values of blades between 0º and 30º side face angles at varying speeds and coconut sizes. It has an average dehusking capacity of 2.56 coconut fruits per minute. The increase in values at higher speed was due to the lower time of dehusking attained during operation. In addition, increase in values at bigger coconut sizes might also be due to a faster time taken for the dehusking blades to touch and penetrate the samples as compared with small coconut sizes.

The variation in dehusking efficiency at different treatment combinations was determined. Based on the result, the highest mean dehusking efficiency of 95% were observed on both medium and large coconut samples using dehusking blades with 0º blade side angles and with crankshaft speeds of 50 and 70 rpm; respectively. On the other hand, lowest mean dehusking efficiency of 79.6% was noted on small coconut samples using blades with 35º blade side angles operating at lower speed. It can also be observed that using dehusking blade with 0º blade side angle had a mean efficiency of about 94% compared with the 81% and 79% efficiencies for

15º and 30º blade side angles; respectively under varying coconut sizes and crankshaft speeds. This suggests that dehusking efficiency was affected by blade side angle followed by the crankshaft speed and coconut size. Generally, dehusking efficiency increases with decreasing blade side angle but increasing crankshaft speed and coconut size. This might be due to the earlier time of penetration and piercing actions of blades with 0º side face angles and thus were able to accommodate and detached more coconut husk fibers as compared with 15 º and 30 º side face angles. Furthermore, this might also explain the increase in efficiency as affected by both the crankshaft speed and coconut size.

Results showed that high mean shell breakage (17%) occur on large coconut fruits at higher blade side angles and crankshaft speed. This indicate that increases in coconut size, crankshaft speed and blade side angle had corresponding increase of damage on coconut shell. The trend might be due to the deeper penetration of dehusking blades on the coconut husk wherein the blades reached and caused breakage on the coconut shell and meat. This might also be caused by human error in the form of misadjustments on the lifting mechanism thereby miscalculating the safe clearance between the blades and the samples.

Test of Significance

Based from the results as shown in Table 1, five out of six predictor variables had significant effects on the decrease or increase of performance of the prototype machine as they were subjected to the different conditions of the independent variables such as crankshaft speed (rpm), coconut size (mmØ), and blade side angle (degrees). The predictor variables were piercing force, power requirement, dehusking time, capacity and efficiency. However, the effect of the independent variables in terms of coconut shell damage as predictor variable was found to be not significant for both 90% and 95% confidence levels. This means that increases on the number of coconut damage in terms of shell breakage will not be attributed to the increases or decreases on crankshaft speed, coconut size and blade side angle. Further, combination of treatment parameters will have the same effect on the decrease or increase of shell damage.

Result shows that the change in generated force was influenced by the variation in crankshaft speed and blade side angle at 90% and 95% levels of confidence. However, force was not affected by coconut size. This indicates that almost similar load could be applied on whatever sizes of coconut. The data obtained for dehusking force also significantly fit the linear and quadratic models. The total model was significant and the adequacy of the estimated model had a high R^2 value of 0.8173 (Table 2). This also means that variation in force was affected by the blade speed since higher blade speed requires lesser dehusking force. Moreover, dehusking force was also accounted for by the variation in blade side angle. Dehusking blades with lower blade side angles required higher dehusking force which might be due to the larger surface area being in contact with the coconut fruit to facilitate detachment of coconut husk. However, the lack of fit test for the data was significant at 95% confidence level (Table 3). According to Myers (1971) data that signifies lack of fit represents those variations which were generated from sources other than the first-order term, linear term. Lack of fit would indicate that the regression function would not be linear. Rafosala and Madamba (2001) stated that there maybe a number of significant variations that occurred which the random error might not have account for and variations which might be caused by unknown factor that the response model had not taken into account.

The change in power generated on the machine was significantly affected by the blade speed, coconut size, and blade side angle at 90% and 95% confidence levels (Table 1). The data for power significantly fit the linear, quadratic, and cross-product models at 95% level of confidence. The total model was also significant with R^2 value of 0.8584. This means that about 86% of the variation in the response was accounted by the function (Gomez and Gomez, 1984). The unaccounted variability could be attributed to other factors that were not considered in the study. Variation in power was also indicated by the lack of fit test which showed significance at 95% level of confidence (Table 3).

The change in dehusking time was significantly affected by the variation in machine's speed (rpm), coconut size (mmØ), and blade side angle (degrees) at 90% and 95% confidence levels. The data obtained for dehusking time also significantly fit the linear, quadratic, and cross product regression models. The total

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model was also significant and the adequacy of the estimated model had a high R^2 value of 0.85 (Table 2). This also means that the total variation in dehusking time was accounted for by the crankshaft speed (rpm), sizes of coconut (mmØ), and blade side angle (degrees). The variation in dehusking time was affected by the speed of machine since higher speed had contributed to the faster penetration of blades and removal of coconut husk at an earlier time. Further, larger coconut sizes were positioned near the dehusking blades also at an earlier time as compared with smaller ones which resulted to faster removal of coconut husk. Further, the lack of fit test was not significant at 95% confidence level. This suggests that there was little variation in the data obtained as indicated by a low CV value of 10.62%. Hence, the data fit the estimated model (Table 3).

The results of the ANOVA showed that change in shell damage was not significant at 90% and 95% confidence levels. This means that the variation in shell damage could not be attributed to the variation in crankshaft speed, coconut size and blade side angle. Whatever levels of independent parameters could incur damage in the form of broken shell and shattered coconut meat. However, only very minimal damage was recorded or about 1 or 2 for every 10 coconut samples. Occurrence of damaged coconut samples was mostly due to human error particularly on the adjustments of lifting mechanism during operation. The samples were lifted very near to the dehusking blades and were not immediately controlled by bringing a little bit lower that caused the later to penetrate even at the coconut meat. However, damaged coconut would not affect the price of copra since part of the traditional method of copra processing done by coconut farmers was to split dehusked coconut into halves to remove the coconut water before drying.

The dehusking capacity or dehusking rate (number of coconut per minute) was significantly affected by the crankshaft speed, coconut size and blade side angle at 95% confidence level (Table 1). Thus more coconut fruits were dehusked when the machine was operated at higher speed. Further, faster dehusking rates were also observed using higher blade side angles and larger coconut sizes. The data obtained for dehusking capacity also significantly fit the linear and quadratic regression models. The total model was significant and the adequacy of estimated model had a R^2 value of 0.7301 and with 14.67% CV (Table 2). However, the lack of fit test for the data was found to be insignificant which means that the data obtained fit the estimated model (Table 3).

The change in dehusking efficiency was significantly affected by the variation in coconut sizes and blade side angles (Table 1). However, efficiency was found to be not affected by machine's crankshaft speed. Thus, more coconut husks were detached with larger coconut sizes and with lower blade side angles at whatever operating speed of the machine. The data obtained for dehusking efficiency significantly fits the linear and quadratic regression models (Table 2). The total model was also significant with R^2 value of 0.8868. Further, the lack of fit test was not significant which indicate that the data fits the estimated model (Table 3).

Table 1. ANOVA showing the effects of independent parameters on the different response variables.

FACTOR	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	FVALUE	PR>F
Force					
X1	4	717.966326	179.491581	3.52	0.0162*
X2	4	410.335779	102.583945	2.01	0.1140
X3	4	7143.969590	1785.99239	35.05	0.0001*
Power					
X1	4	1.681612	0.420403	3.05	0.0296*
X2	4	10.231296	2.557824	18.53	0.0001*
X3	4	19.714903	4.928726	35.70	0.0001*
Dehusking Time					
X1	4	33.943040	8.485760	38.91	0.0001*
X2	4	9.052960	2.263240	10.38	0.0001*
X3	4	5.595318	1.398830	6.41	0.0006*
Coconut Shell Damage					
X1	4	28.118496	7.029624	0.15	0.9614

X2	4	104.115961	26.028990	0.56	0.6941
X3	4	180.446236	45.111559	0.97	0.4372
Rate/Capacity					
X1	4	9.030124	2.257531	18.00	0.0001*
X2	4	2.917473	0.729368	5.82	0.0011*
X3	4	1.521366	0.380341	3.03	0.0301*
Efficiency					
X1	4	1.910899	0.477725	0.08	0.9886
X2	4	151.510138	37.877534	6.16	0.0007*
X3	4	1573.967163	393.491791	63.98	0.0001*

Note: X_1= Crankshaft Speed, X_2= Coconut Size, X_3= Blade Side Angle

Table 2. Adequacy of estimated model.

FACTOR	DEGREES OF FREEDOM	SUM OF SQUARES	R^2	FVALUE	PR>F
Force					
Linear	3	6844.264489	0.7012	44.77	0.0001*
Quadratic	3	723.939615	0.0742	4.74	0.0071*
Cross Product	3	409.747101	0.0420	2.68	0.0618
Total Model	9	7977.951204	0.8173	17.40	0.0001*
Power					
Linear	3	23.065855	0.6759	55.70	0.0001*
Quadratic	3	3.722793	0.1091	8.99	0.0001*
Cross Product	3	2.503688	0.0734	6.05	0.0020*
Total Model	9	29.292336	0.8584	23.58	0.0001*
Dehusking Time					
Linear	3	20.499362	0.4073	31.33	0.0001*
Quadratic	3	18.951426	0.3765	28.97	0.0001*
Cross Product	3	3.250043	0.0646	4.97	0.0056*
Total Model	9	42.700831	0.8483	21.75	0.0001*
Coconut Shell Damage					
Linear	3	168.853608	0.0890	1.21	0.3212
Quadratic	3	64.054822	0.0338	0.46	0.7132
Cross Product	3	34.050104	0.0179	0.24	0.8653
Total Model	9	266.958533	0.1407	0.64	0.7581
Rate/Capacity					
Linear	3	4.274215	0.2629	11.36	0.0001*
Quadratic	3	7.118754	0.4378	18.92	0.0001*
Cross Product	3	0.479409	0.0295	1.27	0.2982
Total Model	9	11.872379	0.7301	10.52	0.0001*
Efficiency					
Linear	3	1387.730762	0.7298	75.21	0.0001*
Quadratic	3	277.304322	0.1458	15.03	0.0001*
Cross Product	3	21.341605	0.0112	1.16	0.3401
Total Model	9	1686.376689	0.8868	30.47	0.0001*

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Table 3. Lack of fit test for the estimated model.

FACTOR	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	FVALUE	PR>F
Force					
Lack of Fit	4	490.190879	122.547720	2.94	0.0361*
Pure Error	31	1293.192442	41.715885		
Total Error	35	1783.383320	50.953809		
Power					
Lack of Fit	4	1.348451	0.337113	3.00	0.0334*
Pure Error	31	3.483133	0.112359		
Total Error	35	4.831584	0.138045		
Dehusking Time					
Lack of Fit	4	1.011308	0.252827	1.18	0.3374
Pure Error	31	6.621972	0.213612		
Total Error	35	7.633280	0.218094		
Coconut Shell Damage					
Lack of Fit	4	25.263689	6.315922	0.12	0.9736
Pure Error	31	1605.55555	51.792115		
Total Error	35	1630.819244	46.594836		
Rate/Capacity					
Lack of Fit	4	0.162847	0.040712	0.30	0.8766
Pure Error	31	4.225806	0.136316		
Total Error	35	4.388653	0.125390		
Efficiency					
Lack of Fit	4	19.813753	4.953438	0.79	0.5433
Pure Error	31	195.448439	6.304788		
Total Error	35	215.262191	6.150348		

The optimum conditions for the dehusking operation of the prototype machine to attain the optimum performance was obtained using the Response Surface Regression. The main objective in optimizing the dehusking process was to come up with conditions that would generate minimum force and power requirements, faster dehusking time, and high dehusking rate and efficiency; respectively.

Based on the Box and Behnken experimental design, the coded data of the second degree polynomial equations which represent the relationship of the independent parameters and the response variables were presented in Table 4. The coefficients of the predictor equations were calculated. However, only the response variables with significant variation in relation to the independent variables were considered. The predictor equation takes the form of second order polynomial model which evaluated the statistical significance of the independent parameters on the response variables. The function is expressed as:

$$Y_k = ß_{k0} + ß_{k1}X_1 + ß_{k2}X_2 + ß_{k3}X_3 + ß_{k11}X_1^2 + ß_{k21}X_2X_1 + ß_{k22}X_2^2 + ß_{k31}X_3X_1 + ß_{k33}X_3^2 + ß_{k32}X_3 X_2 \quad \text{(Equation 5)}$$

Where: $ß_{kn}$ = constant regression coefficients
Y_k = response variables
X_1 = blade speed, rpm
X_2 = coconut size, mmØ
X_3 = blade side angle, degrees

Table 4 also presents the significant effects of each individual independent variable and their interactions on each of the response variables (Y_1 to Y_5). Results showed that dehusking time (Y_3) was the most affected response variable by the treatment factors and their interactions followed by power (Y_2), dehusking rate (Y_4), dehusking force (Y_1) and efficiency (Y_5). It can be observed that the interactions between the machine's crankshaft speed and coconut size mostly influenced force and power requirements while the interactions between blade side angle and coconut size mostly affected the power, dehusking time and efficiency. Further, quadratic parameters were also found to have caused significant effect on the response variables.

Table 4. Regression coefficients of the second order polynomials describing the relationship of the response variables and independent variables

PARAMETERS	COEF.	Y_1	Y_2	Y_3	Y_4	Y_5
Intercept	β_0	-69.369	36.717**	78.040**	-41.799**	-18.538
X_1	β_1	0.497	0.069	-0.309**	0.181**	-0.102
X_2	β_2	15.465	-3.845**	-6.344**	4.030**	10.223
X_3	β_3	0.988	0.184**	-0.311**	0.101	-0.299
$X_1 * X_1$	β_4	0.015**	0.001	0.003**	-0.002**	0.0005
$X_2 * X_1$	β_5	-0.126**	-0.007**	-0.005	0.003	0.0008
$X_2 * X_2$	β_6	-0.136	0.122**	0.164**	-0.106**	-0.220
$X_3 * X_1$	β_7	-0.002	-0.0003	-0.001	0.0003	-0.0001
X_3 * X2	β_8	-0.069	-0.0098**	0.015**	-0.0041	-0.043*
$X_3 * X_3$	β_9	-0.023**	-0.001**	0.002**	-0.0014**	0.022**

Note: X_1= "Crankshaft Speed", X_2= "Coconut Size", X_3= "Blade Side Angle"
Y_1= "Force", Y_2 = "Power", Y_3 = "Dehusking Time", Y_4="Dehusking Rate", Y_5="Dehusking Efficiency"
*** Significant at 95% confidence level, * Significant at 90% confidence level*

The derived predictor equations describing the relationships of the different significant response variables with the independent variables are presented in equations 7 to 11. The equations convey the responses in terms of the independent parameters used in the experiment. The predictor equations were expressed using significant responses at 90% and 95% levels of confidence. However, all coefficients can be considered also in the models.

Models for Response Variables:

$$Y_1 = -69.369 + 0.497X_1 + 15.465X_2 + 0.988\,X_3 + 0.015\,X_1^2 - 0.126\,X_2\,X_1 - 0.136\,X_2^2 - 0.022\,X_3X_1 - 0.069\,X_3X_2 - 0.023\,X_3^2 \quad \text{(Equation 6)}$$

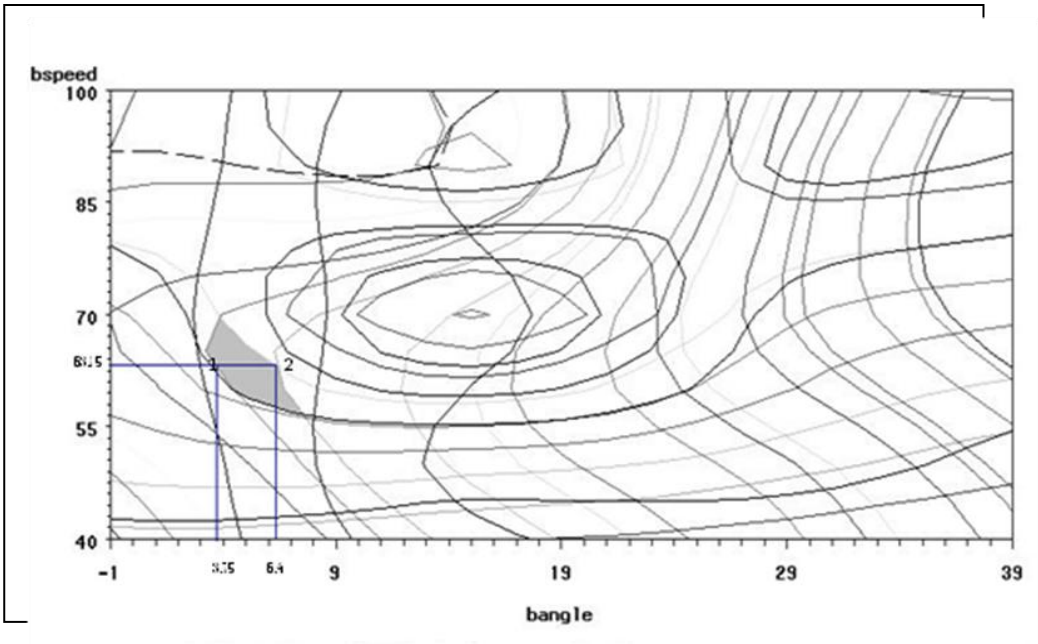
$$Y_2 = 36.717 + 0.069X_1 - 3.845X_2 + 0.184X_3 + 0.001X_1^2 - 0.007X_2X_1 + 0.122X_2^2 - 0.0003X_3X_1 - 0.0098\,X_3X_2 - 0.001\,X_3^2 \quad \text{(Equation 7)}$$

$$Y_3 = 78.040 - 0.309X_1 - 6.344X_2 - 0.311X_3 + 0.003X_1^2 - 0.005X_2X_1 + 0.164X_2^2 - 0.001X_3X_1 - 0.015X_3X_2 + 0.002\,X_3^2 \quad \text{(Equation 8)}$$

$$Y_4 = -41.799 + 0.181X_1 + 4.030X_2 + 0.101X_3 - 0.002X_1^2 + 0.003X_2X_1 - 0.106X_2^2 + 0.0003X_3X_1 - 0.0041X_3X_2 - 0.0014\,X_3^2 \quad \text{(Equation 9)}$$

$$Y_5 = -18.538 - 0.102X_1 + 10.223X_2 - 0.299X_3 + 0.0005X_1^2 + 0.0008X_2X_1 - 0.220X_2^2 - 0.0001X_3X_1 - 0.043X_3X_2 + 0.022\,X_3^2 \quad \text{(Equation 10)}$$

Figures 3 and 4 present the superimposed contour that yielded optimum experimental region. This also showed the different values of the surfaces of the response variables as indicated. Presented in Table 5 are the tabulated ranges of the optimum region of the independent variables. Looking at the optimum region, force and power generated and dehusking time are low while dehusking rate and efficiency are high. Considering the ranges on the levels of factor variables, two optimum region points (point 1 and point 2) were chosen and the values of predicted responses (Table 6) were determined using the developed predicting equations. Moreover, looking at points 1 and 2 at the optimum region in Figure 5 and the values in Table 6, it can be seen that point 2 had exhibited favorable optimum condition as compared to point 1. It has lower force and power requirement, lower dehusking time and higher dehusking rate as compared with point 1 at the optimum region, However while point 2 seemed to be the logical choice for optimum condition but moving towards this region would also result to the decrease in dehusking efficiency.



Figur achine
speed and blade side angle

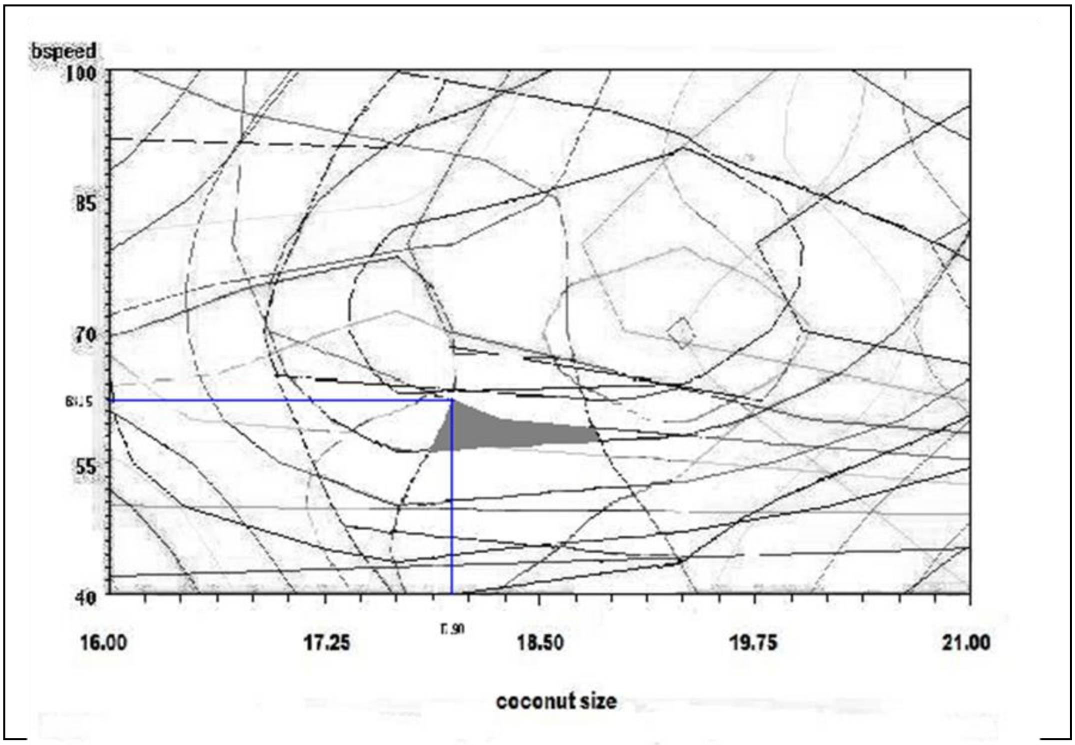


Figure 4. The superimposed optimal experimental region of dependent variables as a function of machine speed and coconut size

4. Conclusion

Development of a functional coconut dehusking machine is an alternative method of improving the efficiency of work in the coconut production and processing. It has a capacity of 240 coconut fruits per hour and can be operated by a single person. An equivalent capacity for a traditional manual dehusking which requires about 2 to 3 persons. However, the technique and skills of the operator spells the difference on the performance of the machine. The operator has to be familiar with the machine's control systems in order to develop the skills needed to attain high machine efficiency. Commercially available coconut dehusking machines are foreign made and they are expensive when imported from other countries. Imported machines may not conform to local requirements in terms of repair and maintenance and most likely problems occur when the unit starts to depreciate, spare parts are hard to find and as result, the unit may just be sold on a junk shop. They may not also be suited to the physical characteristics of coconut varieties found in the country. It is in this light that this study was undertaken to develop a low cost, workable, and portable coconut dehusker that can be used even at remote coconut farms in the country.

In order to attain optimum performance, it is recommended that the machine has to be operated at a crankshaft speed of 63.25 rpm using blade with side angle of 5.43 degrees for dehusking different coconut sizes, which can result to low force requirement, low power consumption, low dehusking time but high dehusking capacity and efficiency.

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