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Development and testing of a husking machine for dry betel nut (*Areca Catechu Linn.*)

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A prototype betel nut husking machine was designed, constructed, tested and evaluated. The design concept was to tear-off the husk of the dry betel nut by exerting differing dynamic friction forces on opposite sides of the nut *via* normal pressure. The prototype featured a hopper into which dry betel nuts were fed, a husking mechanism, and a power drive. The husking mechanism was composed of two identical husking wheels mounted in series. Each husking wheel consisted of a rubber tyre and a concave sieve constructed from steel rods. The dry betel nut was fed into the space between the running tyre surface and the sieve surface of the husking mechanism. When the nut passed through the first wheel, the combined compression and friction force crushed the nut husk and loosened the nut. The husk and nut were further separated by repeating the operation with a second tyre. Results showed that (a) the optimum machine settings, identified by the greatest production score (PS), were characterised by a tyre pressure of 138 kPa, a tyre speed of 440 rpm, and a 15 mm spacing between the surfaces of the tyre and the sieve; (b) the optimal betel nut fruit moisture content was 6.31% w.b. Performance testing of the prototype based on the optimum settings produced the following results: optimally husked full nuts (64.4%); broken nuts (15.2%); unhusked nuts (20.5%). Thus, the PS was 76.9%.

1. Introduction

Betel nut (*Areca Catechu Linn.*), also known as areca nut, has applications as human and animal medicine and is used in the paint and leather industries (Niamhom and Jarimopas, 2005). Thailand in 2003 exported US$ 13.7 m of over-mature betel nut (Niamhom *et al.*, 2006).

In order to make use of the dry betel nut, the nut fruit has firstly to be dehusked into a nut. Fig. 1 depicts the structure of the dry over-mature betel nut fruit. As can be seen, it comprises of a nut firmly attached to a husk on the side that is closest to the stem, while a gap exists on the other side because of the separation of the nut from the husk as a result of loss of moisture.

The mechanical properties of the areca nut in relation to dehusking were studied by Balasubramanian and Panwar (1986). They have found that lateral shear with a rubbing action might be suitable for dehusking the fruit. They have further

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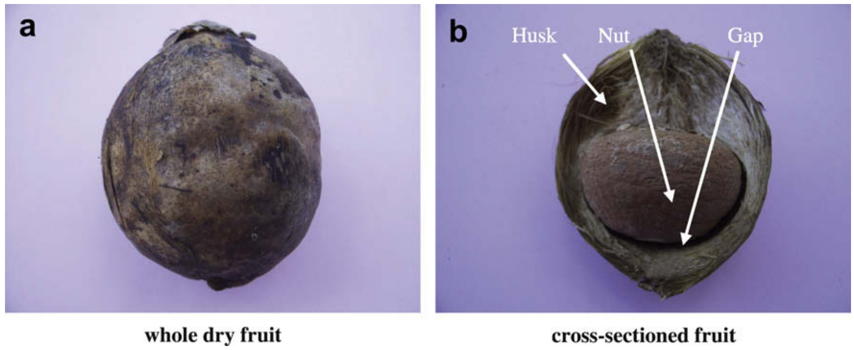

Fig. 1 – Cross-section of a betel nut after 45 days of natural sun drying during the February–March summer season.

noted that the moisture content of the dry fruit should be in the range of 5–6% w.b. for the technique to be most efficiently used.

Prior to this, Baboo (1981) developed a device for dehusking dry areca nut fruit. The device comprised a scissor mechanism, a frame, a platform and a pedal operated lever mechanism. The device, which was operated by two workers, could produce 13.4 kg of areca nut per hour. Earlier still, Wang (1963) proposed a mathematical model for the design of a frictional roller poha-berry husking machine. The model not only indicated that both friction and normal forces caused the husking of the berry but also provided an estimate of roller size.

More recently, a dry betel nut shelling machine developed by a farmer was tested by Jarimopas and Niamhom (2004). The husking mechanism featured one 10-5.00 tyre and a sieve, constructed from steel rods, which was curved under the tyre. The design concept of the shelling machine was similar to the idea proposed by Wang (1963) in that husking was exerted by both friction and normal forces although a point of difference was that husking did not occur between two rollers but through the use of a single rotating tyre and a stationary sieve. However, the sieve – which was supported by a spring – proved to be rather inefficient because it often came loose, causing a high degree of incomplete husking. This experience suggests that the husking process ought to be repeated at least twice in order for the nut to be completely separated from the husk.

In 2007, Niamhom *et al.* introduced a new design for a betel nut fruit husking machine. Its husking mechanism comprised two commercial 10-5.00 rubber tyres hinged adjacent to and parallel with a concave sieve. The tyres were inflated to a pressure of 138 kPa and rotated at 448 rpm. Unfortunately, the percentage of full husked nuts that was produced by this machine was not given, so it is not possible to make judgements about its proper efficiency. Also parameters such as tyre speed, tyre pressure, spacing between the tyre surface and the sieve surface, and the condition of the betel nut (moisture and size) were not given.

In summary, although research has been carried out on betel nut husking it has lacked systematic machine and experimental design, and does not satisfactorily identify the conditions required to produce optimum performance. This research was aimed at correcting these deficiencies.

2. Materials and methods

2.1. Design and operation

2.1.1. *Design*

Fig. 2 provides a schematic diagram of the prototype dry betel nut fruit husking machine. The machine (dimensions: 520 mm W; 920 mm L; 1180 mm H) comprised three parts: a hopper, husking mechanism and power drive. The hopper was a rectangular cone constructed from 1.2 mm steel plate. The husking mechanism comprised two identical husking wheels, each consisting of a 155-10 size rubber tyre and a concave sieve featuring 76 9.5 mm steel rods arranged in parallel with a 15 mm clearance between the rods. The

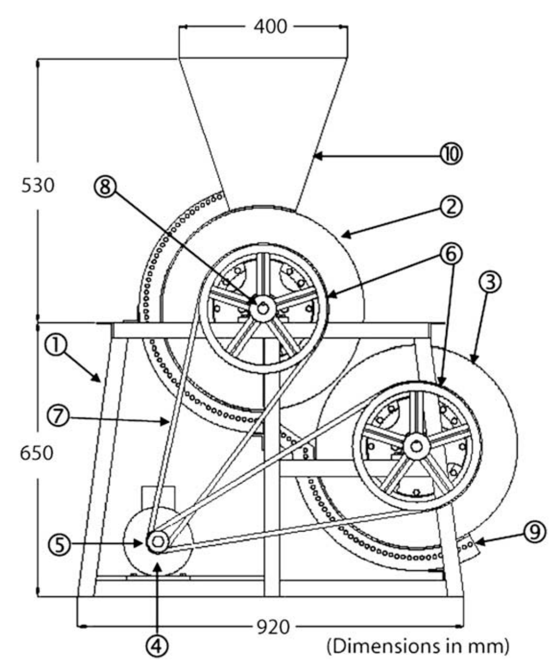

Fig. 2 – Schematic diagram of dry betel nut fruit husking machine. (1 = Frame; 2 = First tyre; 3 = Second tyre; 4 = 220 V 50 Hz 1 Phase 2.2 kW Electric motor; 5 = Driving pulley; 6 = Following pulley; 7 = V-belt; 8 = 25.4 mm Axial shaft; 9 = Steel concave sieve; 10 = Hopper).

rotating tyres and the concave sieve formed the mechanism to husk the dry betel nut fruit. The power drive consisted of a 3 hp, 220 V, 50 Hz electric motor which transmitted mechanical power *via* adjustable pulleys to the first and the second tyres.

2.1.2. *Operation*

Dry over-mature betel nut fruits were continuously and manually fed into the hopper. The fruit was conveyed into the narrow passage between the concave sieve and the tyre surface by the rotating tyre and the weight of the fruit. At the point that contact simultaneously occurred between the fruit surface and tyre on one side and between the fruit surface and the rod surface on the other side, normal pressure occurred which compressed the fruit at both contact points. Because contact occurred while the tyre was rotating, friction was experienced in opposite directions at the contact points. The combined compression and friction crushed the husk of the fruit and loosened the nut. The nut inside the fruit remained intact because the rupture force of the nut was higher than that of the husk.

The tyre continued to roll the crushed fruit along the concave, further compacting the husk and loosening the nut until the fruit reached the end of the concave. However, as experiments have showed that dehusking is usually incomplete after the first tyre stage (Jarimopas and Niamhom, 2004), the partially husked fruit was fed into a second tyre stage, which had the same design and operating conditions as the first. Repeating husking of the partially husked fruit by the second tyre separated the nut from the husk, resulting in complete nut removal.

2.2. *Performance tests*

2.2.1. *Determining the appropriate moisture content of the dry betel nut fruit*

The effect of moisture levels in dry betel nut fruit on the performance of the husking machine was examined in the following way. A sample of fresh yellow over-mature fruit was purchased from an orchard in the Chumphon province, Thailand, and sun-dried on asphalt from February to March 2006. Following this, a subsample of the dried betel nut fruit was collected and grouped into 6 bags during the 4th week of February. Each bag of the subsample contained 60 dry betel nut fruit, which weighed between 15.1–20 g fruit. One sample bag of the dried fruit was then placed in an electric oven (Isotherm, USA) at a temperature of 105 °C for 24 hrs so the moisture level could be measured.

$$\text{Percent moisture} = \frac{\text{Weight of betel nut fruit before drying} - \text{Weight of betel nut fruit after drying}}{\text{Weight of betel nut fruit before drying}} \times 100 \qquad 1$$

The remaining five bags were treated as replicates. Drying of the betel nut continued for another 5 weeks using the procedure described in earlier. Following Niamhom *et al.* (2007), the performance testing was done at constant tyre pressure of 138 kPa and at a speed of 440 rpm. A production score (PS) was introduced to identify the optimal performance based on the total value of the outputted nuts. The PS was defined as follows:

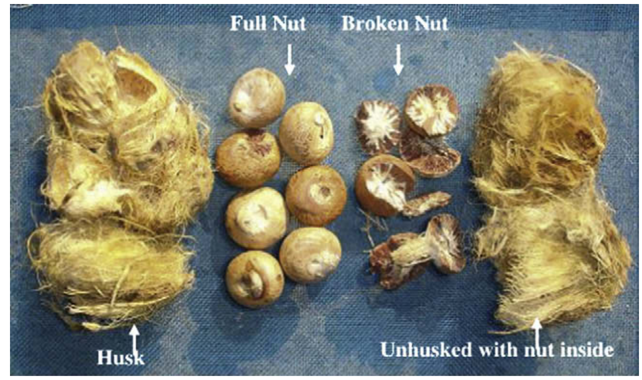

Fig. 3 – Various products of the dry betel nut fruit husking machine

$$\text{PS} = (\text{F} + 0.15\text{B} + 0.5\text{U}) \times 100/\text{number of tested fruit} \qquad 2$$

where F is the number of whole nuts; B is the number of broken nuts; and U is the number of unhusked nuts that were not completely separated from the husk (Fig. 3). Based on information obtained from betel nut producers, the value of a broken nut is about 15% of that of a whole nut, and the value of an unhusked nut is about 50% of a whole nut because of the additional labour cost of removing the husk. Accordingly, if 60 fruits were used in a test, the maximum performance score would be 100. Mechanical husking was performed and evaluated by means of Least Significance Difference (LSD) and Duncan Multiple Range Test (DMRT) techniques.

$$\%\text{full nuts after mechanical husking} = \text{number of full nuts by mechanical husking} \times 100/\text{number of fruits tested}$$

$$\%\text{unhusked nuts} = \text{number of unhusked fruits} \times 100/\text{number of fruits tested}$$

$$\%\text{broken nuts} = 100 - \text{F} - \text{U}$$

2.2.2. *Determining the optimal size of the dry betel nut fruit and husking clearance*

The effect of dry betel nut fruit size on the performance of the husking machine was also determined. The machine settings and the optimal fruit moisture content previously described in Section 2.2.1 were kept constant throughout the test. The control factors included fruit size (small, medium, large) and clearance between the tyre surface and the sieve surface (10, 15, 20 mm). The sizes were defined as follows: small (10–15 g fruit^{-1}); medium (15–20 g fruit^{-1}); large (20–25 g fruit^{-1}). Five replications involving a combination of the control factors were performed. Testing of the husking machine was conducted and evaluated by the use of LSD and DMRT techniques.

2.2.3. Determining the appropriate tyre speed and tyre pressure

Three mechanical parameters of concern governing the machine performance were tyre speed, tyre pressure, and spacing between tyre surface and the concave sieve. The optimal spacing had already been determined from the previous test. This experiment aimed to find the effect of variation of tyre speed (320, 370, 440, 508, and 645 rpm), tyre pressure (0, 69, 138, 207, and 276 kPa) at the constant optimal values for spacing and fruit size obtained described in Section 2.2.2 in this experiment was defined as the continuous feeding of individual fruit into the machine. Sixty fruit of uniform optimal size were processed at a combination of speeds and pressures. Three replications were employed and LSD and DMRT techniques were used for performance analysis.

2.2.4. Continuous operation test

Although the experiment described above involved the insertion of uniformly sized nuts into the hopper, growers in reality prefer to dehusk dry betel nut fruits which vary in size. Accordingly, continuous operation of the husking machine using varying sizes of nuts was tested. The optimal machine conditions and fruit moisture levels described in Sections 2.2.1, 2.2.2 and 2.2.3 were held constant throughout the test. Five replications were performed using 15 kg of variously sized dry betel nuts (615 fruit). The results of the experiment were also statistically evaluated.

3. Results and discussion

3.1. Optimal moisture levels of the dry betel nut fruit

The moisture content of the betel nut samples significantly affected the husking performance at $p < 0.05$ (Table 1). It was found that drier fruit tended to be husked more completely than fruit which was not so dry. This tendency, when moisture content was equal or less than 6.31% w.b., was probably due to the 12% decline in force that is required to rupture the husk of betel nut fruits which has been dried for 5–7 weeks (Niamhom and Jarimopas, 2005). Tests showed that nuts which had a moisture content of 5.45% were 4% less likely to be completely husked, 6% more likely to be left unhusked, and 1.7% less likely to be broken than nuts which had a moisture content of 6.31%. However, because (a) the difference between the PSs at these two moisture levels was found to be insignificant ($p > 0.05$), (b) the PS at the moisture content of 6.31% was higher than that of 5.45% and (c) because of the longer drying time that is required for the nuts to achieve a 5.45% moisture level, it was concluded that the optimal moisture level was 6.31% w.b. This value is in agreement with the suggestion by Balasubramanian and Panwar (1986) that the moisture level of nuts during husking should measure 5–6% w.b..

Table 2 – Effect of size and spacing between the tyre surface and the concave sieve surface on the % of full nuts

Size	Spacing (mm)		
	10	15	20
Small	*58.00 ± 1.39^{b}	56.67 ± 1.18^{b}	51.33 ± 3.20^{a}
Medium	61.33 ± 2.17^{c}	73.00 ± 1.39^{e}	68.67 ± 3.61^{d}
Large	66.00 ± 3.03^{d}	76.33 ± 2.74^{f}	72.00 ± 1.39^{e}

* Means in the same column with different letters are significantly different at $p < 0.05$.

3.2. Proper fruit size and husking spacing

Size and spacing significantly affected the performance of the husking machine at $p < 0.05$ (Tables 2–5). At each spacing tested, the larger fruit tended to be husked more completely. This probably occurred because the larger fruit fitted the spacing more accurately and thus husking became more complete (Table 2). Likewise, at each tested spacing (Table 4), the larger nuts were least likely to remain unhusked. The greatest % full nuts of medium and large fruit occurred at 15 mm spacing.

Conversely, the greatest % of unhusked fruits occurred with small fruit because these nuts did not make firm contact with the tyre and the sieve. At 20 mm spacing, small fruit

Table 1 – Effect of moisture of betel nut fruit on husking machine performance

Fruit moisture (% w.b.)	Full nuts %	Broken nut %	Unhusked fruit %	PS**
12.67	*13.00 ± 3.80^{a}	7.67 ± 3.84^{a}	79.33 ± 6.93^{e}	53.82 ± 1.45 ^{a}
9.88	24.67 ± 5.58 ^{b}	7.67 ± 5.22^{a}	67.67 ± 9.40^{d}	59.65 ± 2.42^{b}
7.57	38.67 ± 5.19^{c}	5.33 ± 3.61^{a}	56.00 ± 6.41^{c}	67.47 ± 2.85^{c}
6.31	54.67 ± 6.60^{d}	8.00 ± 2.17^{a}	37.33 ± 6.08^{ab}	74.53 ± 3.67^{d}
5.78	56.67 ± 5.40^{d}	9.67 ± 3.80^{a}	33.67 ± 2.47^{a}	74.95 ± 3.95^{d}
5.45	50.67 ± 7.13^{d}	6.33 ± 2.98^{a}	^{e}43.00 ± 5.45^{b}	73.11 ± 4.36^{d}

* Means in the same column with different letters are significantly different at $p < 0.05$
** Full score = 100.

Table 3 – Effect of size and spacing between the tyre surface and the concave sieve surface on the % of broken nuts

Size	Spacing (mm)		
	10	15	20
Small	*6.00 ± 0.91[a]	6.00 ± 0.91[a]	6.00 ± 0.91[a]
Medium	29.33 ± 2.53[d]	13.00 ± 0.74[b]	12.67 ± 0.91[b]
Large	27.33 ± 0.91[c]	12.67 ± 1.49[b]	12.67 ± 1.49[b]

* Means in the same column with different letters are significantly different at $p < 0.05$.

made minimal contact, which resulted in unhusked fruit levels of 42.7% (the maximum value recorded).

With regard to broken nuts (Table 3), 6% of small fruit fell into this category regardless of spacing. A value of 12.7% was recorded for medium and large fruit, with spacings of 15 and 20 mm being recorded as insignificantly different. The PS was highest at a spacing of 15 mm regardless of whether the nuts were of medium or large size (Table 5). Based on the PSs, the optimal fruit size was ''medium'' and spacing was 15 mm. Medium nuts were preferred to large nuts because medium nuts occur most commonly in nature.

3.3. *Optimal tyre speed and pressure*

Tyre speed (S) and pressure (P) significantly affected the characteristics of husking performance at $p < 0.05$ (Tables 6–9). The high % of full nuts was of most interest because the production of full nuts indicates high production efficiency. At each tested speed (Table 6), the increase in tyre pressure increased the full nut percentage. This might be because tyres which are inflated more fully tend to be more rigid, and rigidity exerts more compression and shearing force on the dry betel nut fruit.

It was also found that increases in speed at each tyre pressure tested increased the % of full nuts. Higher speeds had the effect of creating additional power shearing on the betel fruit. At a speed of 440 rpm and pressures ranging from 69 to 276 kpa, full nut percentage tended to peak.

However, at each of the tested speeds, higher tyre pressures increased the % of broken nuts (Table 7). High tyre rigidity also caused more breakages in dry nuts. Furthermore, at each of the tested tyre pressures, increases in speed increased the % of broken nuts. The lowest % of broken nuts (11.7%) occured at a speed of 440 rpm and a pressure of 138 kPa.

Table 4 – Effect of size and spacing between the tyre surface and the concave sieve surface on the % of unhusked nuts

Size	Spacing (mm)		
	10	15	20
Small	*36.00 ± 1.90[e]	37.33 ± 1.90[e]	42.67 ± 3.03[f]
Medium	9.33 ± 0.91[ab]	14.00 ± 1.49[c]	18.67 ± 3.80[d]
Large	6.67 ± 2.64[a]	11.00 ± 1.49[b]	15.33 ± 2.47[c]

* Means in the same column with different letters are significantly different at $p < 0.05$.

Table 5 – Effect of size and spacing between the tyre surface and the concave sieve surface on PS

Size	Spacing (mm)		
	10	15	20
Small	*76.90 ± 0.67[c]	76.23 ± 0.45[c]	73.57 ± 1.74[b]
Medium	70.40 ± 1.94[a]	81.95 ± 0.77[ef]	79.90 ± 1.81[d]
Large	73.43 ± 1.71[b]	83.73 ± 1.86[ef]	81.57 ± 0.64[de]

* Means in the same column with different letters are significantly different at $p < 0.05$.

Finally, at each speed level tested, increases in tyre pressure decreased the % of unhusked fruit; likewise, at each tyre pressure tested, increases in speed also decreased % of unhusked fruit (Table 8). Thus, tyre speed and tyre pressure significantly influenced PSs.

The optimum conditions for these variables following experimentation (at $p < 0.05$ (Table 9)) were found to be S = 440 rpm and P = 138 kPa, which produced a maximum PS of 82.1. These values were reached with several considerations in mind. Firstly, PS at the same speed and a higher tyre pressure of 207 kPa was 81.85%, which was insignificantly different. Furthermore, a tyre pressure of 276 kPa was at the upper limit recommended by the manufacturer, which suggested that running the tyre at a lower pressure value would be safer. Also with regard to tyre speed, it was felt that running it at 440 rpm would also reduce electricity costs.

3.4. *Continuous husking performance*

Table 10 illustrates the performance of a husking machine continuously processing mixed size dry betel nuts at the constant optimum conditions of 440 rpm tyre speed, 138 kPa tyre pressure, and husking spacing of 15 mm. More than ten times the fruit samples used in the initial short experimental tests were used for each replicate. The results showed that the percentages of full nuts, broken nuts and unhusked fruit were 64.4, 15.2, and 20.15% respectively. Accordingly, PS was calculated as 76.9% and it was determined that 110 kg of full nuts could be produced per hour. In contrast, growers using standard methods today produce output which comprise 60% of full nuts, 4.5% of broken nuts, 5% of unhusked nuts and 30.5% of husk at a production rate of 30 kg day^{-1}.

4. Conclusion

A prototype dry betel nut husking machine was developed and optimum machine conditions, which were identified by the greatest PS, were characterized by (a) tyre pressure of 138 kPa; tyre speed of 440 rpm; and spacing between the tyre surface and the concave sieve surface of 15 mm; and (b) an optimal nut moisture content of 6.31% w.b. Performance testing of the prototype based on the optimum settings revealed that husking mixed size fruit produced output comprising 64.4% of

Table 6 – Percentage of full nut production computed by DMRT

Tyre speed (rpm)	Tyre pressure (kPa)				
	0	69	138	207	276
320	*26.00 ± 1.90^{a}	42.00 ± 2.47^{c}	51.33 ± 2.17^{d}	55.00 ± 2.64^{def}	57.33 ± 4.50^{efg}
370	26.67 ± 2.64^{a}	54.33 ± 4.35^{de}	59.00 ± 3.25^{fgh}	60.00 ± 2.64^{gh}	62.33 ± 0.91^{hi}
440	28.00 ± 3.61^{a}	66.00 ± 6.30^{ijk}	72.33 ± 2.53^{mn}	74.67 ± 2.98^{n}	73.67 ± 1.39^{mn}
508	36.00 ± 5.08^{b}	65.33 ± 2.17^{ij}	69.67 ± 2.17^{klm}	69.67 ± 2.17^{klm}	71.33 ± 1.39^{mn}
645	41.00 ± 2.79^{c}	66.67 ± 1.67^{jkl}	70.67 ± 1.90^{lmn}	70.33 ± 4.15^{lmn}	73.00 ± 1.39^{mn}

* Means with different letters are significantly different at $p < 0.05$.

Table 7 – Percentage of broken nuts computed by DMRT

Tyre speed (rpm)	Tyre pressure (kPa)				
	0	69	138	207	276
320	*4.67 ± 1.39^{a}	10.00 ± 2.64^{bc}	11.00 ± 1.49^{bcd}	11.33 ± 1.39^{bcd}	21.67 ± 4.25^{hi}
370	5.00 ± 1.18^{a}	14.33 ± 1.90^{defg}	13.00 ± 2.17^{cdef}	12.00 ± 1.39^{bcd}	23.33 ± 1.67^{hi}
440	5.33 ± 3.61^{a}	15.33 ± 5.70^{efg}	11.67 ± 1.18^{bcd}	15.67 ± 1.90^{fg}	22.00 ± 0.75^{hi}
508	8.67 ± 2.17^{b}	16.00 ± 1.90^{fg}	15.67 ± 1.90^{fg}	20.67 ± 1.90^{h}	23.67 ± 1.83^{hi}
645	14.33 ± 1.49^{defg}	17.00 ± 1.39^{g}	16.33 ± 2.17^{fg}	24.33 ± 3.65^{i}	22.67 ± 2.79^{hi}

* Means with different letters are significantly different at $p < 0.05$.

Table 8 – Percentage of unhusked fruit computed by DMRT

Tyre speed (rpm)	Tyre pressure (kPa)				
	0	69	138	207	276
320	*69.33 ± 3.25^{l}	48.00 ± 2.98^{j}	37.67 ± 1.49^{i}	33.67 ± 3.61^{hi}	21.00 ± 0.91^{f}
370	68.33 ± 3.73^{l}	31.33 ± 4.62^{gh}	28.00 ± 5.06^{g}	28.00 ± 2.74^{g}	14.33 ± 1.49^{de}
440	66.67 ± 6.67^{l}	18.67 ± 5.32^{ef}	16.00 ± 1.90^{de}	9.67 ± 2.17^{bc}	4.33 ± 1.49^{a}
508	55.33 ± 7.11^{k}	18.67 ± 2.17^{ef}	14.67 ± 2.74^{de}	9.67 ± 1.39^{bc}	5.00 ± 1.18^{a}
645	44.67 ± 2.47^{j}	16.33 ± 1.39^{de}	13.00 ± 3.42^{cd}	5.33 ± 2.74^{ab}	4.33 ± 1.49^{a}

* Means with different letters are significantly different at $p < 0.05$.

Table 9 – PS of the husking machine performance computed by DMRT

Tyre speed (rpm)	Tyre pressure (kPa)				
	0	69	138	207	276
320	*61.37 ± 0.52^{a}	67.50 ± 1.76^{c}	71.82 ± 1.51^{d}	73.53 ± 1.12^{def}	71.08 ± 3.72^{d}
370	61.58 ± 0.97^{a}	72.15 ± 2.31^{d}	74.95 ± 1.19^{efg}	75.80 ± 1.49^{fgh}	73.00 ± 0.89^{de}
440	62.13 ± 1.29^{a}	77.63 ± 4.65^{ghij}	82.08 ± 1.58^{l}	81.85 ± 2.01^{kl}	79.13 ± 0.78^{ij}
508	64.97 ± 1.88^{b}	77.07 ± 1.50^{ghij}	79.35 ± 1.33^{ijk}	77.60 ± 1.66^{ghij}	77.38 ± 1.25^{ghij}
645	65.48 ± 1.70^{bc}	77.38 ± 1.19^{ghij}	79.62 ± 0.95^{jkl}	76.65 ± 3.16^{ghi}	78.57 ± 1.66^{hij}

* Means with different letters are significantly different at $p < 0.05$.

Table 10 – Performance of husking machine at continuous operation

Mechanical husking of full nut (%)	Broken nuts (%)	Unhusked fruits (%)	PS
64.36 ± 3.22	15.15 ± 0.96	20.49 ± 2.35	76.87 ± 1.93

full nuts, 15.2% of broken nuts, and 20.5% of unhusked nuts at a PS of 76.9%.

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