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Effects of disc peg drum parameters on maize shelling performance of an axial flow shelling unit

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Abstract Reserch finding showed that an increase in guide vane inclination and rotor speed resulted in increased maize shelling efficiency and decreased total loss, whereas feed rate and moisture content did not statistically affect shelling efficiency or total loss. A higher moisture content resulted in increased grain breakage while rotor speed, feed rate, and guide vane inclination did not statistically affect grain breakage. A higher moisture content, guide vane inclination, feed rate, and rotor speed tended to increase power consumption. Meanwhile, a higher moisture content, guide vane inclination, and rotor speed tended to increase specific energy consumption whereas an increased feed rate tended to reduce it. Optimal parameters of the drum were a moisture content of less than 17 %wb, a feed rate of less than 2 tons/hr, a guide vane inclination of more than 87 degrees, and a rotor speed of more than 12 m/s.

Keywords: Drum, Shelling efficiency, Maize shelling unit, Maize shelling performance

Introduction

Maize is an economically important crop, especially due to its use in the world's animal feed industry (Oladejo *et al.*, 2011; Farjam *et al.*, 2014). In addition to animal feed, it can be used for products such as starch, oil, glue, ethanol, and industrial alcohol (Haros *et al.*, 2003; Naqvi *et al.*, 2011; Wallington *et al.*, 2012; Ranum *et al.*, 2014). Currently, there is growing worldwide demand for maize. The United States, China and Brazil have expanded their use of arable land and now produce approximately 563 of the 717 million metric tons of maize per year (Ranum *et al.*, 2014). When maize is sold on the market, high moisture content and temperature can become problematic, causing fungal toxins that yield low-quality produce and are

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harmful to human and animal health (Suleiman *et al.*, 2018; Burger *et al.*, 2013; Giorni *et al.*, 2008). Therefore, farmers must carefully maintain the quality of maize seeds (Fox and O'Hare, 2017), particularly during maize harvesting and shelling, production processes that are significant with respect to transporting, manufacturing, and storing (Chuan-Udom, 2013).

Most plantations in Asia, whether large or small, have both flatland and hillside slope areas. Therefore, maize harvesters must be modified in order to be adaptable to all areas as multi-functional combine harvesters (Srison *et al.*, 2016a; Chuan-Udom, 2013). However, modifications have resulted in a large, expensive, heavyweight machine, and most unpeeled maize shelling uses peg teeth, which results in a high total loss and grain breakage (Chuan-Udom *et al.*, 2018; Chuan-Udom, 2013). There is a need for a small, lightweight harvesting machine for maize harvests in each area.

A maize shelling unit with a length not exceeding 900 mm has been developed with the capacity to be attached to a tractor (Saeng-ong *et al.*, 2015; Srison *et al.*, 2016b). Although certain modifications and adjustments have already been made to the shelling unit, there is still a need to study other factors affecting shelling performance in order to reduce total loss and grain breakage and to maintain the quality of produce.

Srison *et al.* (2016b) studied design factors affecting losses and power consumption and found that rotor speed affected total loss, feed rate affected power consumption, and moisture content affected grain breakage. Chuan-Udom *et al.* (2018) studied peg-tooth spacing and guide vane inclination and found that both the guide vane inclination and the moisture content caused losses. Saeng-ong *et al.* (2015) found that increasing the guide vane inclination and the rotor speed resulted in decreased losses. Miu and Kutzbach (2008a), who studied modeling and simulation of grain threshing, asserted that modeling could be helpful in the design and optimization of the functional parameters of the threshing unit and in the development of control software and process controllers. Miu and Kutzbach (2008b) studied modeling and simulation of grain threshing and found that modeling could increase design efficiency and reduce testing time and costs.

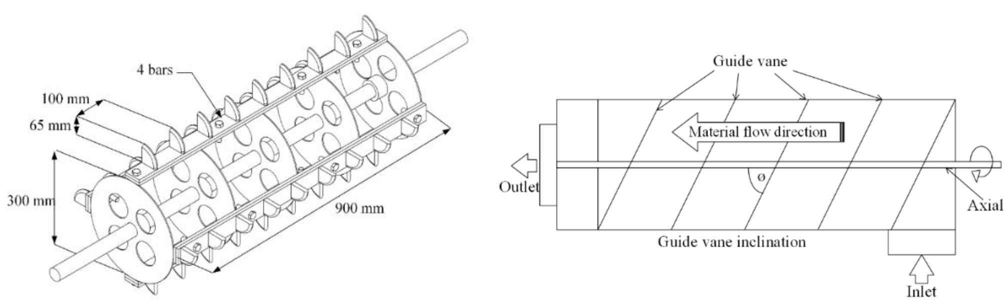
Research showed that defining parameters is important for the maize shelling process. Therefore, this research was aimed to study the effects of disc peg drum parameters on maize shelling performance of an axial flow shelling unit. The study targeted higher design efficiency aimed to develope the control software, reduced testing time and costs, and maintained the quality of the maize seeds while also reducing total loss from maize shelling.

Materials and methods

Maize shelling unit

This study was conducted using an axial flow maize shelling machine housed by the Applied Engineering for Important Crops of the North East Research Group, Khon Kaen University, Thailand. The shelling unit was 1.90 m long, with a width of 1.83 m and height of 1.6 m. It was divided into nine slots (100-mm widths), as shown in Figure 1. The machine used a disc peg drum with peg tooth thickness of 11 mm, 100-mm spacing between teeth, and 50-mm radius of teeth curvature, as shown in Figure 2(a). It had speed control with variable speed drive; the feed rate of the conveyor belt could be controlled with an adjustable guide vane inclination, as shown in Figure 2(b).

Figure 1. Maize shelling unit



(a) (b)

Figure 2. Shape of the disc peg drum (a) and guide vane inclination (b) of the maize shelling unit

Factors tests and experimental design

The study used pacific maize and a concave clearance of 15 mm to test the following factors: moisture content, guide vane inclination, feed rate, and rotor speed. Each factor was tested at five different levels, as shown in Table 1. As suitable for the number of factors and factor levels, central composite design (CCD) was selected for the experiment (Berger and Maurer, 2002), as shown in Table 2. Indicator values described shelling efficiency, total loss, grain breakage, power consumption, and specific energy consumption.

Table1 . Independent factor levels

Variable	Levels				
	-2	-1	0	1	2
MC (%wb)	14	17	20	23	26
GI (degree)	81	83	85	87	89
FR (t/hr)	1.25	1.50	1.75	2.00	2.25
RS (m/s)	6	8	10	12	14

Note: MC = moisture content, GI = guide vane inclination, FR= feed rate, RS = rotor speed

Table 2. Experimental units according to central composite design for shelling efficiency, total loss, grain breakage, power consumption, and specific energy consumption

Expt. No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
MC (%wb)	2	1	1	1	1	1	1	1	1	0	0	0	0	0	0
GI (degree)	0	1	1	1	1	-1	-1	-1	-1	0	0	0	0	0	0
FR (t/hr)	0	1	1	-1	-1	-1	1	-1	1	0	0	0	0	0	0
RS (m/s)	0	1	-1	1	-1	-1	-1	1	1	0	0	0	0	0	0
Expt. No.	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
MC (%wb)	0	0	0	0	0	0	-1	-1	-1	-1	-1	-1	-1	-1	-2
GI (degree)	0	0	0	0	2	-2	1	1	1	1	-1	-1	-1	-1	0
FR (t/hr)	-2	2	0	0	0	0	1	-1	1	-1	-1	1	-1	1	0
RS (m/s)	0	0	-2	2	0	0	1	1	-1	-1	-1	-1	1	1	0

Note: MC = moisture content, GI = guide vane inclination, FR= feed rate, RS = rotor speed

Testing method

Each test used 10 kg of maize. Data was collected on the maize cobs discharged from the maize husk outlet. The materials were separated and cleaned to determine the weight of the grains and to calculate shelling efficiency and total loss. A sample of 1 kg was taken randomly from the chute (nine slots) in order to estimate grain breakage. Power consumption used in shelling was measured using a torque sensor (SG-Link Model; Lord Micro Strain; Williston, VT, USA).

Data analysis

The independent factor levels (moisture content, guide vane inclination, feed rate, and rotor speed) is shown in Table 1. These independent factor levels were analyzed for how they affected shelling efficiency levels, total loss, grain breakage, power consumption, and specific energy consumption. Parameter efffects were analysed using the response surface method (RSM) and central composite design (CCD) with coefficients of R^2 and P-values obtained by Design-Expert Software (version 7; Stat-Ease Inc; Minneapolis, MN, USA.).

Indicator values

Indicator values were shelling efficiency, total loss, grain breakage, power consumption, and specific energy consumption. Calculations were based on the Regional Network for Agricultural Machinery (RNAM, 1995). Shelling efficiency was expressed as

$$SE = [(A+B)/W_T]\ 100\ \times, \qquad (1)$$

where A represents the grain weight of all the shelled grain at the main grain outlet (g), B represents the weight of the shelled grain at the husks and cobs outlet (g), and W_T represents the weight of all fed grain (g). The total loss was expressed as

$$TL = [(M_1+M_2)/W_T] \times 100, \qquad (2)$$

where M_1 represents the grain weight of the shelled grain at the cobs and husks outlet (g) and M_2 represents the grain weight of the unshelled grain at the cobs and husks outlet (g). Grain breakage was estimated as

$$GB = [(M_B)/W_R] \times 100, \qquad (3)$$

where M_B represents the grain weight of all grain breakage (g) and W_R represents the random weight of shelled grain after cleaning. Power consumption was calculated from torque gauging, using the equation

$$P = (2\times\pi\times n\times T)/60, \qquad (4)$$

where n represents the rotor speed (rpm) and T represents the electric motor torque (N-m). Specific energy consumption was calculated as

$$SEC = P/FR, \quad (5)$$

where P represents power consumption (watts), and FR represents the feed rate of the feeder in tons/hr.

Results

The effects of moisture content, guide vane inclination, feed rate, and rotor speed on shelling efficiency

The cubic model produced the highest R^2 value of 0.8997, followed by the quadratic, 2FI, and linear models with values of 0.8385, 0.7667, and 0.6898, respectively (Table 3). The adjusted R^2 was similar to the predicted R^2. While the cubic model had the highest R^2 value, aliases in the model prevented it from being selected for analyzing the effect on shelling efficiency. The linear model was found to have a P-value of less than 0.05, and was therefore selected for factor analysis.

Table 3. Analysis of optimal model when using central composite design to determine effects of disc peg drum parameters on shelling efficiency

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Sequential Model Sum of Squares						
Mean vs Total	279200	1	279200			
Linear vs Mean	**269.74**	**4**	**67.44**	**13.9**	**< 0.0001**	**Suggested**
2FI vs Linear	30.05	6	5.01	1.04	0.4292	
Quadratic vs 2FI	28.09	4	7.02	1.67	0.2094	
Cubic vs Quadratic	23.92	8	2.99	0.5337	0.8011	Aliased
Residual	39.22	7	5.6			
Total	279600	30	9320.97			
Source	**Std. Dev.**	**R^2**	**Adj R^2**	**Pred R^2**	**PRESS**	
Model Summary Statistics						
Linear	**2.2**	**0.6898**	**0.6402**	**0.5639**	**170.52**	**Suggested**
2FI	2.19	0.7667	0.6439	0.5235	186.31	
Quadratic	2.05	0.8385	0.6878	0.4958	197.14	
Cubic	2.37	0.8997	0.5845	0.6134	151.18	Aliased

The results indicated that in terms of the disc peg drum's effect on shelling efficiency, guide vane inclination and rotor speed were significant factors, with a P-value of less than 0.05, making them suitable factors for the regression model (Table 4). Moisture content and feed rate did not significantly affect shelling efficiency, showing a P-value more than 0.05. Therefore, the regression model of the parameters' effect on shelling efficiency can be expressed as

$$SE = 31.182+0.585GI+1.557RS \tag{6}$$

Table 4 Variance analysis of disc peg drum parameters' effect on shelling efficiency

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	269.74	4	67.44	13.9	< 0.0001	significant
MC	2.67	1	2.67	0.5497	0.4654	
GI	32.85	1	32.85	6.77	0.0153	
FR	1.47	1	1.47	0.303	0.5869	
RS	232.75	1	232.75	47.98	< 0.0001	

Note: MC = moisture content, GI = guide vane inclination, FR= feed rate, RS = rotor speed

Based on Equation (6), response surface plots were developed to show the effect of guide vane inclination and rotor speed (Figure 3) on shelling efficiency.

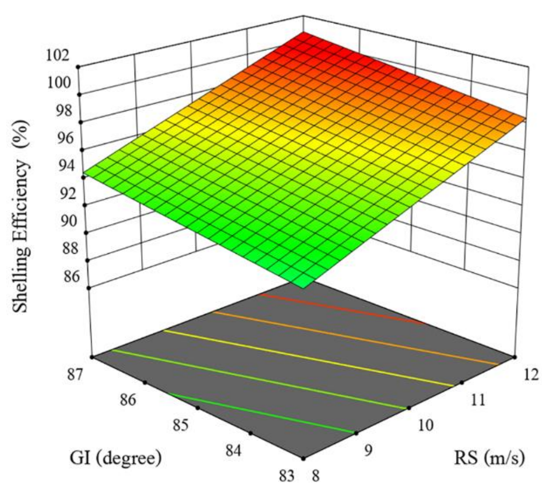


Figure 3. Response surface plot of shelling efficiency as affected by guide vane inclination and rotor speed

The effects of moisture content, guide vane inclination, feed rate, and rotor speed on total loss

The cubic model had the highest R^2 value of 0.9200, followed by the quadratic, 2FI, and linear models with values of 0.8699, 0.8072, and 0.7372, respectively (Table 5). The adjusted R^2 was similar to the predicted R^2. While the cubic model had the highest R^2 value, aliases in the model prevented it from being selected for analyzing the effect on total loss. The linear model was found to have a *P*-value of less than 0.05 and was therefore eligble for use in factor analysis.

Table 5. Analysis of optimal model when using central composite design to determine effects of disc peg drum parameters on total loss

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Sequential Model Sum of Squares						
Mean vs Total	1104.01	1	1104.01			
<u>Linear vs Mean</u>	**<u>410.17</u>**	**<u>4</u>**	**<u>102.54</u>**	**<u>17.53</u>**	**<u>< 0.0001</u>**	**<u>Suggested</u>**
2FI vs Linear	38.93	6	6.49	1.15	0.3731	
Quadratic vs 2FI	34.94	4	8.73	1.81	0.1793	
Cubic vs Quadratic	27.82	8	3.48	0.5466	0.7922	Aliased
Residual	44.54	7	6.36			
Total	1660.41	30	55.35			
Source	**Std. Dev.**	**R^2**	**Adj R^2**	**Pred R^2**	**PRESS**	
Model Summary Statistics						
<u>Linear</u>	**<u>2.42</u>**	**<u>0.7372</u>**	**<u>0.6951</u>**	**<u>0.6284</u>**	**<u>206.76</u>**	**<u>Suggested</u>**
2FI	2.38	0.8072	0.7057	0.599	223.11	
Quadratic	2.2	0.8699	0.7486	0.5935	226.18	
Cubic	2.52	0.92	0.6684	0.7792	122.84	Aliased

In terms of how the disc peg drum affected total loss, the results indicated that guide vane inclination and rotor speed had a significant effect with a P-value of less than 0.05, making these factors suitable for the regression model (Table 6). Moisture content and feed rate did not significantly affect total loss, with a P-value of more than 0.05. Therefore, the regression model of the parameters' effect on total loss can be expressed by the equation

$$TL=96.571-0.844GI-1.875RS \tag{7}$$

Table 6. Variance analysis of disc peg drum parameters' effect on total loss

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	410.17	4	102.54	17.53	< 0.0001	significant
MC	1.43	1	1.43	0.2446	0.6252	
GI	68.41	1	68.41	11.7	0.0022	
FR	2.83	1	2.83	0.4837	0.4932	
RS	337.5	1	337.5	57.7	< 0.0001	

Note*:* MC = moisture content, GI = guide vane inclination, FR= feed rate, RS = rotor speed

Response surface plots were developed from Equation 7 showing the effect of guide vane inclination and rotor speed (Figure 4) on total loss.

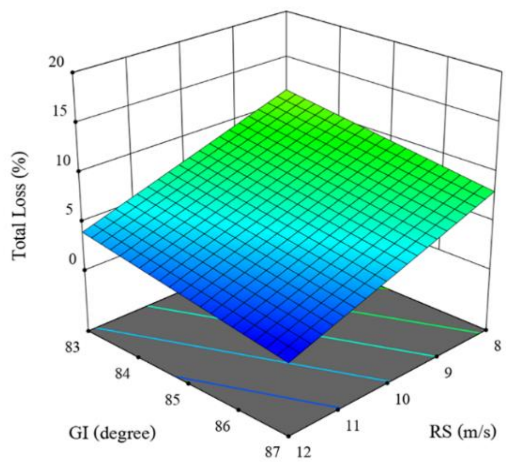


Figure 4. Response surface plots of total loss as affected by guide vane inclination and rotor speed

The effects of moisture content, guide vane inclination, feed rate, and rotor speed on grain breakage

The cubic model had the highest R^2 value of 0.9314, followed by the quadratic, 2FI, and linear models with values of 0.8275, 0.7801, and 0.7503, respectively (Table 7). The adjusted R^2 was similar to the predicted R^2. While the cubic model had the highest R^2 value, aliases in the model prevented it from being selected for analyzing the effect on grain breakage. The linear model was found to have a P-value of less than 0.05 and was therefore eligble for use in factor analysis.

Table 7. Analysis of optimal model when using central composite design to determine effects of disc peg drum parameters on grain breakage

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Sequential Model Sum of Squares						
Mean vs Total	24.26	1	24.26			
Linear vs Mean	**2.28**	**4**	**0.5692**	**18.78**	**< 0.0001**	**Suggested**
2FI vs Linear	0.0905	6	0.0151	0.4294	0.8502	
Quadratic vs 2FI	0.1439	4	0.036	1.03	0.4235	
Cubic vs Quadratic	0.3153	8	0.0394	1.33	0.3616	Aliased
Residual	0.2082	7	0.0297			
Total	27.3	30	0.91			
Source	**Std. Dev.**	**R^2**	**Adj R^2**	**Pred R^2**	**PRESS**	
Model Summary Statistics						
Linear	**0.1741**	**0.7503**	**0.7103**	**0.6381**	**1.1**	**Suggested**
2FI	0.1874	0.7801	0.6644	0.3774	1.89	
Quadratic	0.1868	0.8275	0.6665	0.2534	2.27	
Cubic	0.1724	0.9314	0.7158	-0.7276	5.24	Aliased

In terms of how the disc peg drum affected grain breakage, the results indicated that moisture content had a significant effect with a P-value of less than 0.05, making it suitable for the regression model (Table 8). Moisture content, feed rate, and rotor speed did not significantly affect grain breakage, with a P-value of more than 0.05. Therefore, the regression model of the parameters' effect on grain breakage can be expressed by the equation

$$GB = 0.100MC - 1.095 \quad (8)$$

Table 8. Variance analysis of disc peg drum parameters' effect on grain breakage

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	2.28	4	0.5692	18.78	< 0.0001	significant
MC	2.15	1	2.15	70.86	< 0.0001	
GI	0.058	1	0.058	1.91	0.1788	
FR	0.0241	1	0.0241	0.7939	0.3814	
RS	0.0468	1	0.0468	1.54	0.2255	

Note*:* MC = moisture content, GI = guide vane inclination, FR= feed rate, RS = rotor speed

From Equation 8, response surface plots were developed to show the effect of moisture content on grain breakage (Figure 5).

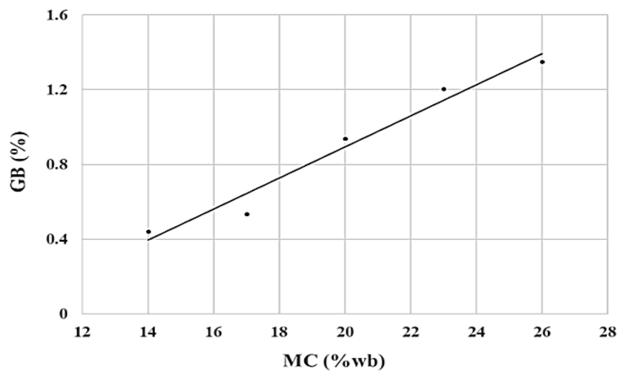


Figure 5. The effect of moisture content on grain breakage

The effects of moisture content, guide vane inclination, feed rate, and rotor speed on power consumption

The cubic model had the highest R^2 value of R^2 0.8845, followed by the quadratic, 2FI, and linear models with values of 0.7378, 0.6347, and 0.5431, respectively (Table 9). The adjusted R^2 was similar to the predicted R^2. While the cubic model had the highest R^2 value, aliases in the model prevented it from being selected for analyzing the effect on power consumption. The linear model was found to have a P-value of less than 0.05 and was therefore eligble for use in factor analysis.

Table 9. Analysis of optimal model when using central composite design to determine effects of disc peg drum parameters on power consumption

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Sequential Model Sum of Squares						
Mean vs Total	34960000	1	3.5E+07			
<u>Linear vs Mean</u>	**<u>703800</u>**	**<u>4</u>**	**<u>175900</u>**	**<u>7.43</u>**	**<u>0.0004</u>**	**<u>Suggested</u>**
2FI vs Linear	118700	6	19788.3	0.7942	0.5859	
Quadratic vs 2FI	133600	4	33390.2	1.47	0.2594	
Cubic vs Quadratic	190200	8	23770.3	1.11	0.451	Aliased
Residual	149700	7	21384			
Total	36250000	30	1208000			
Source	**Std. Dev.**	**R^2**	**Adj R^2**	**Pred R^2**	**PRESS**	
Model Summary Statistics						
<u>Linear</u>	**<u>153.9</u>**	**<u>0.5431</u>**	**<u>0.47</u>**	**<u>0.3145</u>**	**<u>888400</u>**	**<u>Suggested</u>**
2FI	157.85	0.6347	0.4424	0.194	1044000	
Quadratic	150.52	0.7378	0.493	-0.4032	1818000	
Cubic	146.23	0.8845	0.5215	-12.091	1.7E+07	Aliased

In terms of how the disc peg drum affected power consumption, the results indicated that moisture content, guide vane inclination, feed rate, and rotor speed had a significant effect, making all of these factors suitable for the regression model (Table 10). Therefore, the regression model of the parameters' effect on power consumption can be expressed by the equation

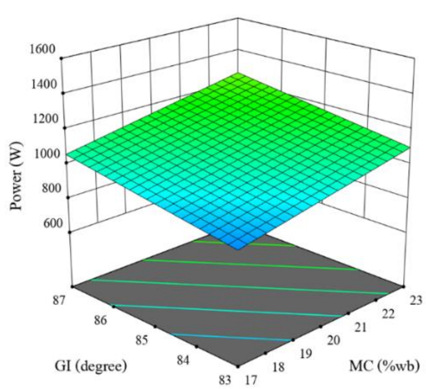
$$P = 33.636MC+40.493GI+239.680FR+47.416RS-3928.769 \tag{9}$$

Table 10. Variance analysis of disc peg drum parameters' effect on power consumption

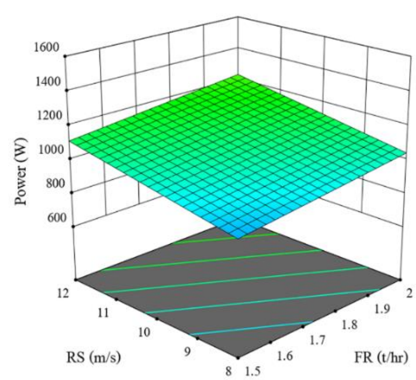
Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	703800	4	175900	7.43	0.0004	significant
MC	244400	1	244400	10.32	0.0036	
GI	157400	1	157400	6.65	0.0162	
FR	86169.75	1	86169.75	3.64	0.068	
RS	215800	1	215800	9.11	0.0058	

Note***:*** MC = moisture content, GI = guide vane inclination, FR= feed rate, RS = rotor speed

From Equation 9, response surface plots were developed to show the effect of moisture content, guide vane inclination, feed rate, and rotor speed on power consumption, as shown in Figure 6 (guide vane inclination and moisture content, rotor speed and feed rate), Figure 7 (rotor speed and guide vane inclination, guide vane inclination and feed rate) and Figure 8 (rotor speed and moisture content, feed rate and moisture content).

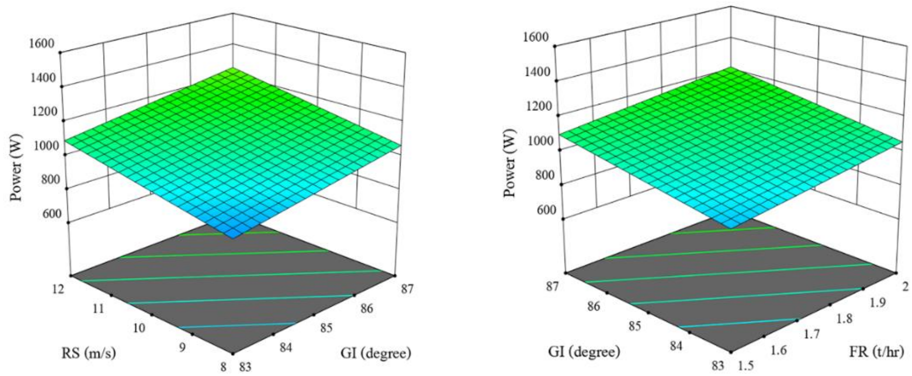


(a)



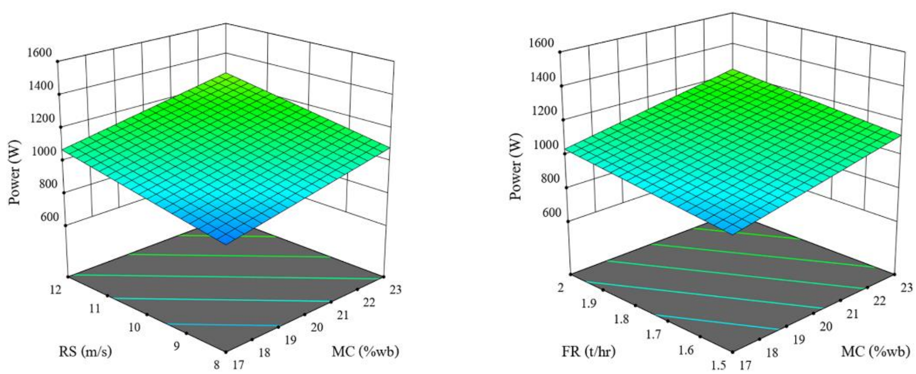
(b)

Figure 6. Response surface plots of power consumption as affected by (a) guide vane inclination and moisture content; (b) rotor speed and feed rate



(a) (b)

Figure 7. Response surface plots of power consumption as affected by (a) rotor speed and guide vane inclination; (b) guide vane inclination and feed rate



(a) (b)

Figure 8. Response surface plots of power consumption as affected by (a) rotor speed and moisture content; (b) feed rate and moisture content

The effects of moisture content, guide vane inclination, feed rate, and rotor speed on specific energy consumption

The cubic model had the highest R^2 value of 0.9103, followed by the quadratic, 2FI, and linear models with values of 0.7853, 0.6868, and 0.5897, respectively (Table 12). The adjusted R^2 was similar to the predicted R^2. While the cubic model had the highest R^2 value, aliases in the model prevented it from being selected for analyzing the effect on specific energy consumption**.** The linear model was found to have a P-value of less than 0.05 and was therefore eligble for use in factor analysis.

Table 13. Analysis of optimal model when using central composite design to determine effects of disc peg drum parameters on specific energy consumption

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Sequential Model Sum of Squares						
Mean vs Total	11650000	1	1.2E+07			
Linear vs Mean	**287000**	**4**	**71755.8**	**8.98**	**0.0001**	**Suggested**
2FI vs Linear	47291.25	6	7881.88	0.9823	0.4642	
Quadratic vs 2FI	47958.11	4	11989.5	1.72	0.1977	
Cubic vs Quadratic	60851.44	8	7606.43	1.22	0.403	Aliased
Residual	43641.04	7	6234.43			
Total	12140000	30	404700			
Source	**Std. Dev.**	**R^2**	**Adj R^2**	**Pred R^2**	**PRESS**	
Model Summary Statistics						
Linear	**89.38**	**0.5897**	**0.524**	**0.3876**	**298100**	**Suggested**
2FI	89.58	0.6868	0.522	0.3184	331800	
Quadratic	83.46	0.7853	0.585	-0.1432	556500	
Cubic	78.96	0.9103	0.6286	-8.8314	4786000	Aliased

In terms of how the disc peg drum affected specific energy consumption, the results indicated that moisture content, guide vane inclination, feed rate, and rotor speed had a significant effect on specific energy consumption, with a P-value of less than 0.05 (Table 14). Therefore, the regression model of the parameters' effect on specific energy consumption can be expressed by the equation

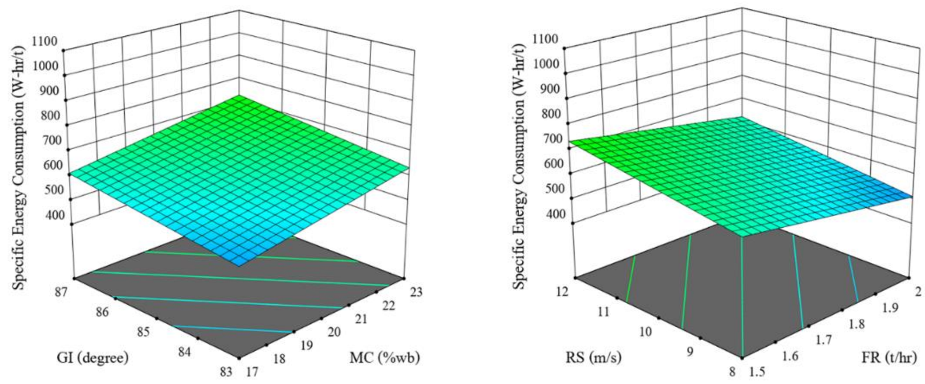
$$SEC = 19.456MC+23.469GI-226.253FR+28.062RS-1645.379 \quad (10)$$

Table 14. Variance analysis of disc peg drum parameters' effect on specific energy consumption

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	287000	4	71755.81	8.98	0.0001	significant
MC	81760.03	1	81760.03	10.23	0.0037	
GI	52876.97	1	52876.97	6.62	0.0164	
FR	76785.86	1	76785.86	9.61	0.0047	
RS	75600.37	1	75600.37	9.46	0.0050	

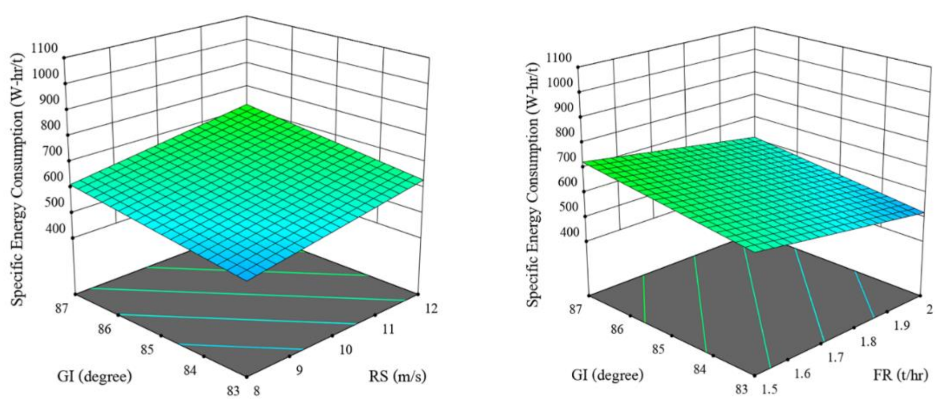
Note: MC = moisture content, GI = guide vane inclination, FR= feed rate, RS = rotor speed

From Equation 10, response surface plots were developed to show the effect of moisture content, guide vane inclination, feed rate and rotor speed on specific energy consumption, as shown in Figure 9 (guide vane inclination and moisture content, rotor speed and feed rate), Figure 10 (guide vane inclination and rotor speed, guide vane inclination and feed rate) and Figure 11 (rotor speed and moisture content, feed rate and moisture content).



(a) (b)

Figure 9. Response surface plots of specific energy consumption as affected by (a) guide vane inclination and moisture content; (b) rotor speed and feed rate



(a) (b)

Figure 10. Response surface plots of specific energy consumption as affected by (a) guide vane inclination and rotor speed; (b) guide vane inclination and feed rate

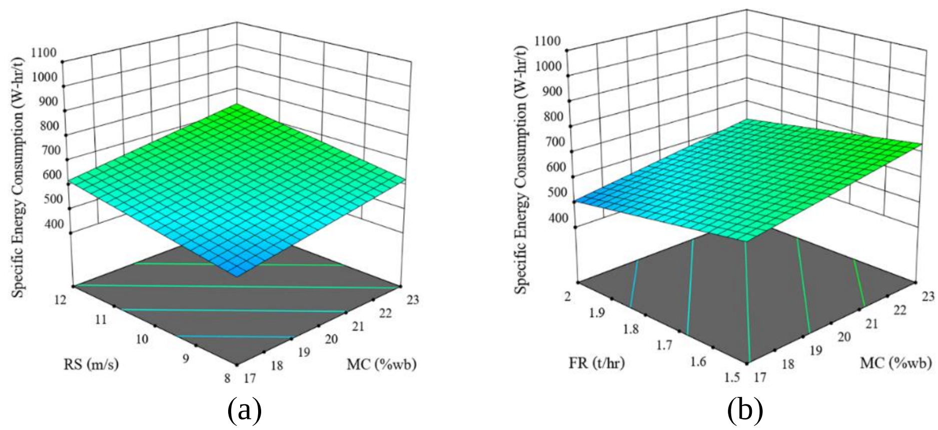


Figure 11. Response surface plots of specific energy consumption as affected by (a) rotor speed and moisture content; (b) feed rate and moisture content

Discussion

The effects of moisture content, guide vane inclination, feed rate, and rotor speed on shelling efficiency

The findings showed that increased guide vane inclination improved shelling efficiency, as lower speeds caused the time to increase. Moreover, an increased rotor speed created a higher impact force on the grain, also leading to increased efficiency. These results are consistent with Saeng-ong *et al.* (2015), who found that an increase in guide vane inclination caused the maize to remain longer in the shelling unit, resulting in increased shelling of maize. Chuan-Udom (2013) found that an increase in the guide vane inclination caused a decrease in the axial movement speed of the maize in the shelling unit, resulting in lower shelling losses. Ukatu (2006) found that increased rotor speed tended to increase shelling efficiency and Yu *et al.* (2015) found that an increased drum rotation rate tended to increase shelling rates. Regardless, it was clear that in the present study, an increased guide vane inclination and rotor speed caused increased efficiency.

The effects of moisture content, guide vane inclination, feed rate and rotor speed on total loss

The results indicated that an increase in guide vane inclination decreased total loss, as a decrease in movement speed led to longer shelling times**.** This finding is consistent with Saeng-ong *et al.* (2015), who concluded that increased guide vane inclination tended to decrease total loss. Chuan-Udom *et al.* (2018) also found that increased guide vane inclination and rotor speed decreased total loss. Srison *et al.* (2016b) found that increased rotor speed resulted in decreased total loss and found that a higher guide vane inclination and rotor speed decreased total loss. Moreover, the high rotor speed created a high centrifugal force in the chamber and this also helped to decrease total loss in this study.

The effects of moisture content, guide vane inclination, feed rate and rotor speed on grain breakage

The results showed that higher moisture content increased grain breakage due to higher moisture content potentially creating effective adhesion between the grain and cob. This adhesion led to easy breakage of the grain. This finding is in line with Al Sharifi *et al.* (2019), Steponavicius *et al.* (2018), and Wacker (2005), who also found that high moisture content led to increased grain breakage.

The effects of moisture content, guide vane inclination, feed rate and rotor speed on power consumption

The present study showed that increased moisture content, guide vane inclination, feed rate, and rotor speed caused the power consumption to increase, as high moisture content caused a stickier surface between the grain and cob. Increased guide vane inclination resulted in lower movement speeds, making for longer shelling times. Meanwhile, an increased feed rate resulted in a higher amount of material in the shelling unit. Also, a low rotor speed caused the shelling unit to jam. Increasing the rotor speed would solve this problem by increasing grain movement. The grain would then have a high-speed impact with the unit, and the seed would be easily separated from the cob. Al Sharifi *et al.* (2019) found that increased guide vane inclination and rotor speed caused power consumption to increase; Srison *et al.* (2016b) concluded that increased moisture content caused power consumption to increase; and El-Desukey *et al.* (2007) found that increased rotor speed tended to increase energy requirements.

The effects of moisture content, guide vane inclination, feed rate and rotor speed on specific energy consumption

The reserch showed that increased moisture content and guide vane inclination, due to good adhesion between grain and cob, increased shelling time and impact force, in turn increasing specific energy consumption. Furthermore, a higher feed rate caused the specific energy consumption to decrease, because the amount of material increased without a change in shelling time. Also, increased rotor speed, due to increasing the amount of material, led to increased specific energy consumption. Therefore, the rotor speed should be increased to shell maize. Saeng-ong *et al.* (2015) found that specific energy consumption increased if the rotor speed increased but declined when feed rate increased.

Finally, this study's analysis of outcomes on shelling efficiency, total loss, grain breakage, power consumption, and specific energy consumption showed that optimal working conditions for a maize sheller with a disc peg drum include a moisture content of less than 17% wb, guide vane inclination of over 87 degrees, a feed rate of less than 2 tons/hr, and a rotor speed of over 12 m/s.

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