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Factors affecting sunflower threshing performance of a small axial flow threshing unit

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Abstract

The small axial flow threshing unit design for mounting on tractors tractor was necessary to study the design factors for the threshing unit to have high performance, and low cost of the machine. The objective of this research was to study the factors affecting sunflower threshing performance of a small axial flow threshing unit. Moisture content of the grain and extraneous material were 14.26% and 62.83% respectively. The grain to material other than grain ratio was 1.49 at a feed rate was 1,200 kg/h. The results showed that peg-tooth clearance had no statistically significant effect on threshing performance, but grain purity (GP) increased with decreased peg-tooth clearance. Thus, decreased peg-tooth clearance affected grain breakage, while the threshing unit required a higher specific energy consumption (SEC), but threshing performance was not affected at a statistically significant level. Furthermore, reducing peg-tooth clearance and concave clearance did not affect threshing efficiency, percentage of broken grains breakage, and power requirements, but specific energy consumption was higher while losses decreased. Optimal parameters of threshing at maximum performance resulted in losses and grain breakage of no more than 2%. Threshing efficient was not less than 95%. Therefore, a concave rod clearance of not more than 25 mm, peg-tooth clearance of the threshing unit of between 125 mm and 150 mm, concave clearance and peg-tooth clearance were not more than 10 mm is recommended to farmers who may operate this unit.

Keywords: Sunflower, Threshing unit, Axial flow threshing, Threshing performance

1. Introduction

The Sunflower is the world's 4th most important oil crop [1-4] since sunflower oil is of high quality and is very useful [5]. At the present time, sunflowers are produced in more than 80 countries. Until recently, the Ukraine is the largest producer and Russia is the second-largest producer, with production volumes of 17.5 and 15.5 Gg, respectively. Currently, the EU and Argentina produces 10.4 and 3.4 Gg, respectively. It was very important for worldwide economics such as food oil industries, alternative bioenergy, and medical [5]. In Thailand, the production volume is 25,000 Mg, making the country a significant sunflower producer. Demand for sunflower oil is increasing due to growth in the world's population [6]. In commerce, there must be a trading standard to maintain the quality of grain. This includes seed moisture levels, impurities, grain breakage, and presence of fungi. If production standards are not met, the grain will be damaged and negatively affect consumers [7-9].

At present, agricultural areas in Asia, including Thailand, engage in small-scale farming. Here, farmers plant crops in rotation, alternately cultivating sunflowers, corn and soybean. Therefore, researchers develop tools to harvest a variety of products with a goal of producing lower-cost harvesting equipment [10-14], which is the most significant cost in the production process. It is one of the Three Pillars of Sustainability [15-25]. Conventional combine harvesters available in Thailand are large, expensive, and difficult to maintain. Their size is not suitable for the small plots of Thailand. Harvesters that are lightweight, easy to maintain, and that can harvest serval crops are necessary in Thai agriculture. In particular, tractor-mounted combine harvesters increase the utilization of tractors [12, 26, 27].

The threshing unit is the heart of this machine's operation. It must be small and lightweight with an axial flow threshing action so that it can be designed to be small and compact [28]. In 2018, Chansrakoo and Chuan-Udom [29] studied the factors affecting a small axial flow threshing unit for soybean production. The designed equipment used a 0.48 m diameter threshing drum that was 0.70 m long to examine the effect of concave clearance, peg-tooth clearance with guide vanes, rotor speed, and feed rate. They found direct impacts upon threshing performance. In 2016, Srisorn et al. [10, 11] found that the statistically significant factors affecting losses in an axial flow corn threshing were concave and peg-tooth clearance. Both studies developed equipment that could be attached to small tractors.

In 2019, Idris et al. [30] studied the efficiency of a multi-crop thresher for small traditional paddy production in Nigeria. This equipment was used for stationary threshing, was electric powered with a specific peg-tooth threshing drum designed by Ojediran et al. [31] and Ajav and Ojediran [32]. It was developed as part of threshing drum employing guide vane inclination. The efficacy of threshing, grain breakage, grain purity, and grain losses were compared with a prototype. It was found that the threshing unit was effective, grain purity was higher, and the percent broken grain decreased [30]. Grain purity depends on design of the threshing system [33]. In most threshing systems, there will be 3-13% losses of grains with 4-10% broken grains when processing sunflowers [34, 35].

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In 2020, Ali et al. [36] studied the factors affecting an axial flow threshing unit design of a sunflower threshing unit. They found that, generally, a larger combine harvester will have an effective threshing of not more than 95% and not more than 2% broken grains. Thus, understanding the key elements influencing post-harvest grain loss during the sales process in Thailand would aid in the better design of intervention measures to reduce grain loss and support the sustainable development of the grain supply.

The main design factors considered in the current study are peg-tooth clearance (PC), concave rod clearance (CR), and concave clearance (CC) in a small axial flow threshing unit. The objective of grain threshing must be a maximum of 2% losses [37] and grain breakage of no more than 2% [36] while threshing efficiency should not be less than 95% [4, 36]. This research aims to study the use of an axial flow threshing unit for sunflower grains.

2. Materials and methods

2.1 Equipment

The axial flow sunflower threshing unit at the Applied Engineering for Important Crops of the Northeast Research Group of Khon Kaen University in Thailand was shown in Figure 1(a). The threshing drums were 0.93 m in diameter and 0.36 m long. The threshing drums had peg-tooth clearance with four adjustment levels, as shown in Figure 1(b). Structural design of the peg-toothed rasp bar is shown in Figure 1(c). The concave rods enabled threshed grain to fall into the concave clearance with kernels diverted into one of nine grains chutes is shown in Figure 1(d). Each of the chutes was about 100 mm wide. The threshing unit was powered by a 5 HP electric motor to control rotor speed.

(a) (b) (c) (d)

Figure 1 (a) Axial flow threshing machine, (b) Structural design of peg-toothed rasp bar, (c) Structural design of concave rods, and (d) The chutes for kernels under threshing units

2.2 Factors studied and experimental design

The study of factors affecting sunflower threshing performance considered five levels of concave rod clearance (CR), which was the distance between the rod as shown in Figure 2(a); 10, 15, 20, 25, and 30 mm, respectively. Peg-tooth clearance (PC), which was the distance between peg-tooths, as shown in Figure 2(b), had five adjustment levels; 50, 75, 100, 125, and 150 mm, respectively, with another five levels of concave clearance (CC), which was the distance between the rod and the peg-tooth as shown in Figure 2(c); 5, 10, 15, 20, and 25 mm, respectively. The experimental design, a central composite design (CCD), is given in Table 1.

(a) (b) (c)

Figure 2 (a) Concave rod clearance (CR), (b) Peg-tooth clearance (PC), and (c) Concave clearance (CC)

Table 1 Central composite design matrix

Expt. No	CR (mm)	PC (mm)	CC (mm)	Comment
1	-2(10)	0(100)	0(15)	Axial points
2	1(25)	1(125)	1(20)	Factorial point
3	1(25)	1(125)	-1(10)	Factorial point
4	1(25)	-1(75)	-1(10)	Factorial point
5	1(25)	-1(75)	1(20)	Factorial point
6	0(20)	-2(50)	0(15)	Axial points
7	0(20)	2(150)	0(15)	Axial points
8	0(20)	0(100)	-2(5)	Axial points
9	0(20)	0(100)	2(25)	Axial points
10	-1(15)	-1(75)	1(20)	Factorial point
11	-1(15)	-1(75)	-1(10)	Factorial point
12	-1(15)	1(125)	1(20)	Factorial point
13	-1(15)	1(125)	-1(10)	Factorial point
14	2(30)	0(100)	0(15)	Axial points
15	0(20)	0(100)	0(15)	Center points
16	0(20)	0(100)	0(15)	Center points
17	0(20)	0(100)	0(15)	Center points

2.3 Testing methodology

The axial flow sunflower threshing machine used sunflower grains. The plants were cut by hand using manual labor. This simulated cutting like a harvesting machine and used a design based on physical characteristics of the material passing into the threshing machine. Figure 3 shows average cuts of 65.86 cm. The cut sunflowers were immediately transported for laboratory testing to reduce the variability due to post-harvest deterioration. The moisture contents of sunflower grains and material other than grains (MOG) were found to be 14.26% and 62.83%, respectively.

(a) (b)

Figure 3 (a) Sunflowers were cut in the field, and (b) Sunflowers were cut by hand with manual labor.

Figure 4 The feed conveyor

The MOG typically consists of sunflower plants such as stalks and leaves when it exits the threshing machine in the case of grain threshing. The grain to material other than grain ratio was 1.49, using a feed rate of 1,200 kg/h, a guide vane inclination of 78°, and 530 rpm constant rotor speed (tangential speed was 10 m/sec). The threshing test for each unit used 5 kg of fresh weight sample material with a conveyor belt control unit to determine the feeding rate. As shown in Figure 4, test number 3 was repeated. The material that fell through the concave clearance was stored into 9 grain chutes and the remaining material passed through the threshing machine. This material was of comprised straw and some seeds. Sunflowers were then sampled in each of the experimental units to determine sunflower threshing performance. The indicators were loss and breakage of seeds. Threshing efficiency was defined using specific power and grain purity.

2.4 Indicating parameters

Indicators efficacy in axial flow threshing are as follows. Threshing loss (TL) was that proportion of the grain weight discharged with the straw discharge the total weight sunflower grains, as given by Eq. (1).

$$TL = \frac{W_1}{W_T} \times 100 \tag{1}$$

where W_1 that total grain weight at the straw discharge chutes (grams) and W_T was the total grain weight (grams).

Grain breakage (GB) was the ratio of the weight of broken grains to the total grain weigh after threshing. The collected grain was collected in nine chutes. The straw output contained a small number of grains. The calculation showing the percentage of broken grains was given as Eq. (2).

$$GB = \frac{M_b}{M_R} \times 100 \tag{2}$$

where *GB* was the quantity of broken grain (%), M_b was the total broken grain weight and W_R was the random weight of a sample grain after threshing.

Threshing efficiency (TE), was the ratio of the weight of sunflower grain and material other-than-grain material to the total weight of sunflower grains after threshing, as shown in Eq. (3).

$$TE = \left(1 - \frac{M_i}{M_i + M_j}\right) \times 100 \tag{3}$$

where *TE* was threshing efficiency (%), M_i was the weight of grain falling through the concave rods to chutes as kernels (grams), M_j was the total sunflower grain discharge at the straw discharge, and W_t was the total weight of sunflower grains in the feed.

The required power required can be calculated from the power of the electric motor used for threshing. It can be classified into two categories, power for threshing and specific energy consumption for threshing.

The power requirement (P) was the power of the electric motor used for threshing for 1 s was shown in Eq. (4).

$$P = \sqrt{3} VIcos\, \emptyset \tag{4}$$

where *P* was the power required by the threshing unit (Watts), *V* was electric potential, *I* was the electric current, and $cos\, \emptyset$ is the power factor.

Specific energy consumption (SEC) was the ratio of electric power to productivity, as shown in Eq. (5).

$$SEC = \frac{P}{FR} \tag{5}$$

SEC was specific threshing power as (W-h/metric ton), *P* (W) was required threshing power requirement and *FR* (metric tons/h) was feeding rate.

Grain purity (GP) was the quantity of sunflower grain by weight that was threshed and falls thought the chutes as kernels after cleaning, as shown in Eq. (6).

$$GP = \frac{P_{pos}}{P_{pre}} \times 100 \tag{6}$$

where *GP* was grain purity (%), P_{pos} was the weight of sunflower grain that was threshed and falls though chutes as kernels after cleaning, P_{pre} was the weight of sunflower grain that was threshed and falls though chutes as kernels before cleaning.

2.5 Data analysis

Analysis of variance (ANOVA) was a statistical technique that can be used to understand the effects of threshing performance of an axial flow threshing unit in conjunction with central composite design (CCD). Design Expert Software, (License No: 1267-1762-5613-EVAL, Stat Ease Inc., Minneapolis, MN, USA was used in this analysis). It was used to indicate sunflower threshing performance employing adjusted R^2 and predicted R^2 values along with analysis of factors affecting threshing performance from response surface methodology (RSM). Correlations of concave clearance (CR), peg-tooth clearance (PC) and concave clearance (CC) were developed.

3. Results and discussion

3.1 The impact of peg-tooth clearance (PC), concave rod clearance (CR), and concave clearance (CC) upon threshing losses

Analysis of variance (ANOVA) in linear regression was employed for design of an axial threshing unit. It was found that peg-tooth and concave clearance (CC) significantly affected percent loss from an axial threshing unit design, p-value < 0.05, while peg-tooth clearance (PC) and concave rod clearance (CR) did not significantly effective the percent lose percentage from an axial threshing unit, p-value > 0.05, as shown in Table 2.

While the appropriate regression parameter (lack-of-fit), it was found that the analytical equation had a p-value > 0.05 [8]. Therefore, a regression model that predicts the percent loss from an axial flow threshing unit, it can be expressed as Eq. (7).

$$TL = 4.63873 - 0.077233CR - 0.16041PC + 1.85825CC \tag{7}$$

The result of analysis of variance of the structural equation model and the statistical value affecting the percent loss from an axial threshing unit found that linear regression produced a relationship with a significantly low p-value (p-value < 0.05). This linear regression had an adjusted R^2 of 0.9312 and a predicted R^2 of 0.8963, as shown in Table 3.

While Eq. (7) is a response surface the correlates the concave rod clearance (CR), peg-tooth clearance (PC) and concave clearance (CC). It was found that the concave clearance (CC) affected the percent loss, as can be clearly seen in Figure 5. When concave clearance (CC) decreases, the percent loss from the axial threshing unit also decreases [8]. The decreasing concave clearance (CC) reduces grain loss from the threshing system, but it increases the efficiency of threshing because the effect of threshing force was increased in the sunflowers between the peg-tooth and the rod [10, 12, 38-40]. As a result, the number of unthreshed sunflower grains was reduced and the threshing power was increased. This is in agreement with the results of Pachanawan et al. [8] and Srison et al. [10].

Table 2 Analysis of variance operating parameters affecting threshing unit loss

Source	Sum of squares	df	Mean square	F Value	p-value prob > F	
Model	55.76	3	18.59	73.19	< 0.0001	significant
A-CR	0.095	1	0.095	0.38	0.5504	
B-PC	0.41	1	0.41	1.62	0.2252	
C-CC	55.25	1	55.25	217.57	< 0.0001	
Residual	3.3	13	0.25			
Lack-of-fit	2.93	11	0.27	1.43	0.4829	not significant
Pure Error	0.37	2	0.19			
Cor Total	59.06	16				

Table 3 Operating parameters and model analysis affecting threshing unit loss

Source	Sequential p-value	Lack-of-fit p-value	Adjusted R-squared	Predicted R-squared	
Linear	< 0.0001	0.4829	0.9312	0.8963	Suggested
2FI	0.8909	0.4002	0.9157	0.8055	
Quadratic	0.4805	0.3668	0.9136	0.7319	
Cubic	0.3875	0.2919	0.9324	-0.3781	Aliased

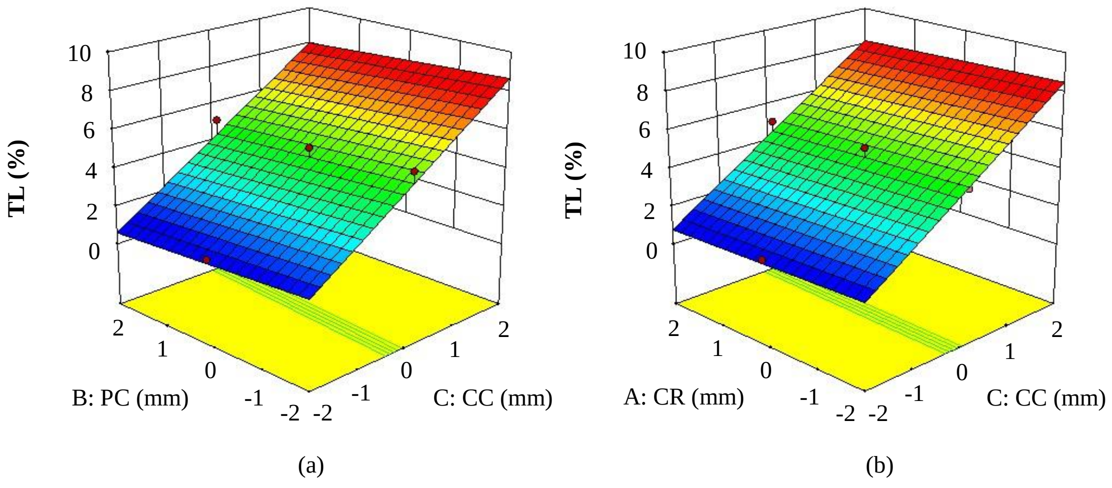


Figure 5 Graphical respond surface affecting of grain loss percentage during sunflower threshing (a) Peg-tooth clearance (PC) and concave clearance (CC) (b) Concave rod clearance (CR) and concave clearance (CC)

3.2 The impact of the factor peg-tooth clearance (PC), concave rod clearance (CR), and concave clearance (CC) on grain breakage

Analysis of variance (ANOVA) and linear regression were used to study how grain breakage was affected by an axial flow sunflower threshing unit. It was found that peg-tooth clearance (PC) significantly affected (p-value < 0.05) the percentage of broken grains in this unit while optimum concave clearance (CC) and concave rod clearance (CR) had no significant effect (p-value > 0.05). as shown in Table 4.

When examining the lack-of-fit of the regression, it was found that the analytical equation had a p-value > 0.05 [8]. Therefore, an appropriate regression model for grain breakage from axial flow threshing unit can be expressed as Eq. (8).

$$GB = 1.10392 - 0.083333CR - 0.33750PC - 0.0625CC \quad (8)$$

The lack-of-fit of the linear regression of grain breakage in axial flow threshing unit showed that normal linear regression produced in the lowest p-value (p-value < 0.05). The corresponding adjusted R^2 was 0.5664 and predicted R^2 was 0.3719 as shown in Table 5.

While Eq. (8) represents the response surface of the concave rod clearance (CR), peg-tooth clearance (PC) and concave clearance (CC). It was found that all three factors had impacted grain breakage (p-value < 0.05). The highest impact was due to peg-tooth clearance. Concave rod clearance and concave clearance had impacts, but they were less than for peg-tooth clearance. This is shown in Figure 6.

As the peg-tooth clearance decreases, threshing power increases. Additionally, the number of broken grains was higher. However, a decrease in the peg-tooth was resulting in an increased power requirement because the effect of the power threshing system was increased between the peg-tooth and sunflowers, but it decreased the weight of seed discharged at the straw discharge, which resulted in a decreased threshing loss, in agreement with the study of Chuan-Udom et al. [28]. The impacts of concave rod clearance (CR) and concave clearance (CC) on grain breakage in the axial flow threshing unit were significant but less than for peg-tooth clearance.

Table 4 ANOVA for operating parameters affecting grain breakage

Source	Sum of squares	df	Mean square	F Value	p-value prob > F	
Model	2	3	0.67	7.97	0.0029	significant
A-CR	0.11	1	0.11	1.33	0.2695	
B-PC	1.82	1	1.82	21.82	0.0004	
C-CC	0.063	1	0.063	0.75	0.4027	
Residual	1.09	13	0.084			
Lack-of-fit	1.05	11	0.095	5.26	0.1705	not significant
Pure Error	0.036	2	0.018			
Cor Total	3.08	16				

Table 5 Model analysis of operating parameters affecting grain breakage

Source	Sequential p-value	Lack-of-fit p-value	Adjusted R-squared	Predicted R-squared	
Linear	0.0029	0.1705	0.5664	0.3719	Suggested
2FI	0.2081	0.1911	0.6350	0.2487	
Quadratic	0.2335	0.2136	0.7062	0.0014	
Cubic	0.0681	0.8383	0.9355	0.9077	Aliased

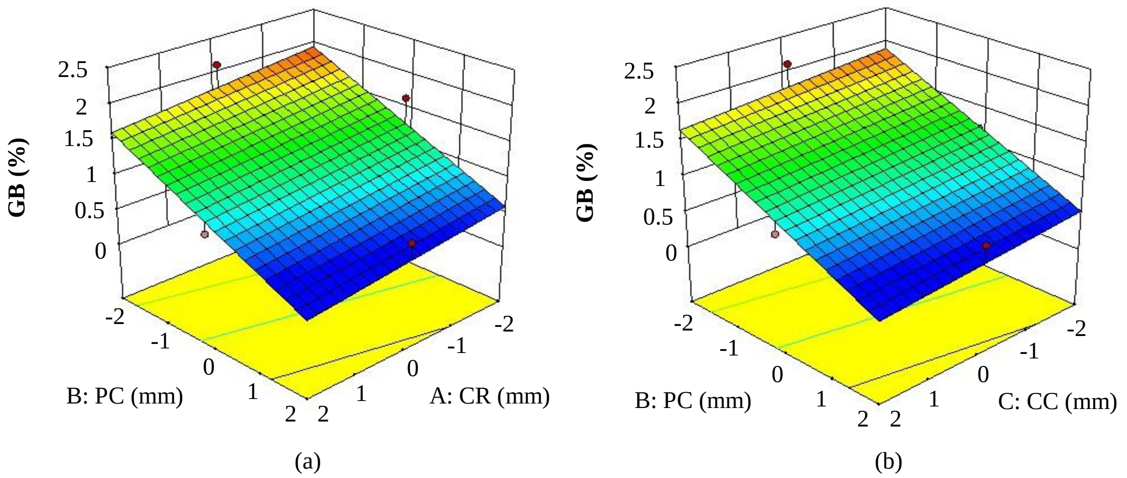


Figure 6 Graphical respond surface affecting of percent grain breakage during sunflower threshing (a) the impact of peg-tooth clearance (PC) and concave rod clearance (CR) (b) the impact of peg-tooth clearance (PC) and concave clearance (CC)

3.3 The impact of peg-tooth clearance (PC), concave rod clearance CR), and concave clearance (CC) on threshing efficiency

Analysis of variance (ANOVA) of threshing efficiency by an axial flow sunflower threshing unit showed that concave clearance (CC) significantly affected threshing efficiency (p-value < 0.05) while peg-tooth clearance (PC) and concave rod clearance (CR) were not statistically significant (p-value > 0.05) as shown in Table 6. The regression lack-of-fit showed that the analytical equation had a value p-value > 0.05. The appropriate regression with the data [8] yields a model for axial flow threshing given by Eq. (9).

$$TE = 96.40125 - 0.085207CR + 0.19580PC - 1.73670CC \quad (9)$$

The resulting lack-of-fit of the linear regression shows the impact upon threshing efficiency in an axial flow threshing unit. It was found that normal linear regression had the lowest p-value (p-value < 0.05). The corresponding adjusted R^2 at 0.8897 and predicted R^2 at 0.8252 are shown in Table 7.

While Eq. (9) represents the response surface of the correlation of factors. *i.e.*, concave rod clearance (CR), peg-tooth clearance (PC), and concave clearance (CC) for threshing efficiency (TE). Concave clearance (CC) significantly impacted (p-value < 0.05) the efficiency of the axial flow threshing unit, as shown in Figure 7. When concave clearance (CC) decreased, the threshing performance increased [8] due to better spacing of the peg-tooth. Decreasing concave clearance increases sunflower yield. Because the effect of the power threshing system was appropriate efficiency between the threshing drum system and sunflowers it results in to increase in the threshing efficiency. Furthermore, the required threshing power increases. As a result, the number of unthreshed sunflower grains decreased [10, 12, 38-40]. In agreement with the work of Pachanawan et al. [8] and Srison et al. [10].

Table 6 ANOVA for operating parameters affecting threshing efficiency

Source	Sum of squares	df	Mean square	F Value	p-value prob > F	
Model	48.99	3	16.33	44.01	< 0.0001	significant
A-CR	0.12	1	0.12	0.31	0.5853	
B-PC	0.61	1	0.61	1.65	0.2209	
C-CC	48.26	1	48.26	130.07	< 0.0001	
Residual	4.82	13	0.37			
Lack-of-fit	4.66	11	0.42	5.07	0.1761	not significant
Pure Error	0.17	2	0.083			
Cor Total	53.81	16				

Table 7 Model analysis of operating parameters on threshing efficiency

Source	Sequential p-value	Lack-of-fit p-value	Adjusted R-squared	Predicted R-squared	
Linear	< 0.0001	0.1761	0.8897	0.8252	Suggested
2FI	0.8651	0.1404	0.8663	0.7153	
Quadratic	0.2461	0.1541	0.8905	0.6150	
Cubic	0.0846	0.3610	0.9720	0.5336	Aliased

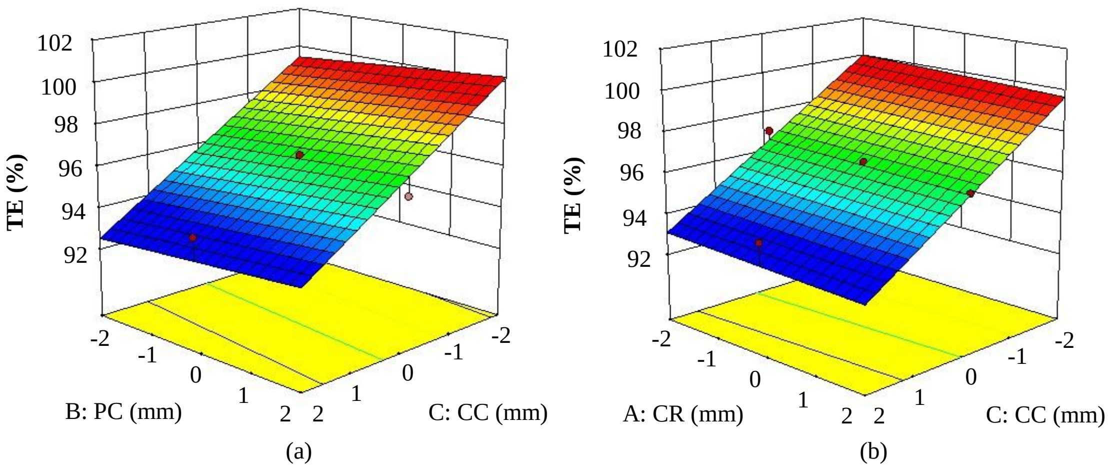


Figure 7 Response surface of efficiency of sunflower threshing for threshing (a) peg-tooth clearance (PC) and concave clearance (CC) (b) concave rod clearance (CR) and concave clearance (CC)

3.4 The impact of peg-tooth clearance (PC), concave rod clearance CR), and concave clearance (CC) upon required threshing power

Analysis of variance (ANOVA) of our linear regression of the power requirements for an axial flow sunflower threshing unit showed that optimal peg-tooth clearance (PC) and concave clearance (CC) affected the power of an axial flow threshing unit in a statistically significant manner (p-value < 0.05). Concave rod clearance (CR) did not affect the power requirements of an axial flow threshing, as shown in Table 8.

Using the appropriate test of the regression (lack-of-fit), it found that it was p-value (0.0493). Since the lack-of-fit nearly reached the p-value > 0.05, we accepted the slight lack-of-fit, as was done in another study [8]. The power requirement in axial flow threshing is expressed as Eq. (10).

$$Power = 230.77451 + 0.89583CR - 8.175PC - 29.25CC \quad (10)$$

The resulting lack-of-fit for normal linear regression of power requirements for an axial flow threshing unit had a low p-value (p-value < 0.05). The corresponding adjusted R^2 at 0.8577 and predicted R^2 at 0.8048 are shown in Table 9.

While Eq. (10) is the response surface, the correlation of concave rod clearance (CR), peg-tooth clearance (PC), and concave clearance (CC) showed that at each level of peg-tooth clearance (PC) at the optimum concave clearance (CC) significantly affected the axial flow threshing unit (p-value < 0.05), as shown in Figure 8. Controlling peg-tooth clearance had a higher impact than controlling the number of peg-teeth [8, 11].

When the optimum concave clearance (CC) was decreased, the concave rod clearance will also decrease, while the required power for the threshing unit increases because the impact between the threshing drum and the sunflower increases as a result of increased threshing power. Thus, the threshing efficiency increased following the power threshing. This is in agreement with the work of Pachanawan et al. [8] and Srison et al. [10].

Table 8 ANOVA for operating parameters affecting power consumption.

Source	Sum of squares	df	Mean square	F Value	p-value prob > F	
Model	14771.13	3	4923.71	33.15	< 0.0001	significant
A-CR	12.84	1	12.84	0.086	0.7734	
B-PC	1069.29	1	1069.29	7.2	0.0188	
C-CC	13689	1	13689	92.16	< 0.0001	
Residual	1930.99	13	148.54			
Lack-of-fit	1913.33	11	173.94	19.7	0.0493	significant
Pure Error	17.66	2	8.83			
Cor Total	16702.12	16				

Table 9 Model analysis of operating parameters on power consumption.

Source	Sequential p-value	Lack-of-fit p-value	Adjusted R-squared	Predicted R-squared	
Linear	< 0.0001	0.0493	0.8577	0.8048	Suggested
2FI	0.8737	0.0385	0.8269	0.6801	
Quadratic	0.1237	0.0522	0.8861	0.5846	
Cubic	0.0826	0.1039	0.9714	0.0719	Aliased

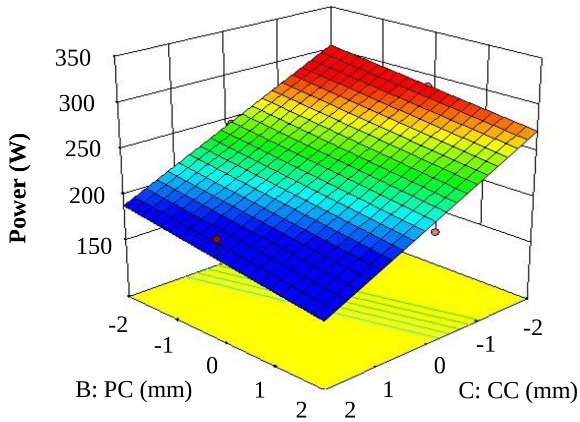


Figure 8 Graph respond surface affected to power requirement of sunflower threshing

3.5 The impact of peg-tooth clearance (PC), concave rod clearance (CR), and concave clearance (CC) on specific energy consumption

Analysis of variance (ANOVA) of our linear regression for specific energy consumption of an axial flow sunflower threshing unit found that peg-tooth clearance (PC) and concave clearance (CC) significantly (p-value < 0.05) affected specific energy consumption (SEC). Concave rod clearance (CR) did not significantly affect the SEC of this unit, as shown in Table 10.

Using the appropriate test of the regression (lack-of-fit), it found that it was p-value (0.0493). Since the lack-of-fit nearly reached the p-value > 0.05, we accepted the slight lack-of-fit as was done in another study [8]. The power requirement in axial flow threshing is expressed as Eq. (11).

$$SEC = 192.31209 + 0.74653CR + 6.81250PC - 24.375CC \quad (11)$$

The resulting lack-of-fit for a normal linear regression of specific energy consumption for an axial flow threshing unit had a low p-value (p-value < 0.05). The corresponding adjusted R^2 at 0.8577 and predicted R^2 at 0.8048 are shown in Table 11.

While Eq. (11) is the response surface of specific energy consumption in an axial flow threshing unit as a function of concave rod clearance (CR), peg-tooth clearance (PC), and concave clearance (CC). It was found that factor peg-tooth clearance (PC) and concave clearance (CC) significantly affected the power requirements of the axial flow threshing unit.

Peg-tooth clearance and concave clearance significantly (p-value < 0.05) impacted specific energy consumption, as shown in Figure 9. Greater power is required with reduced peg-tooth clearance and concave clearance. Thus, the threshing efficiency increased following the required threshing power, which is similar to the result of the impact of PC, CR, and CC upon the required threshing power. This is in agreement with the work of Pachanawan et al. [8] and Srison et al. [10] and Petkevicius et al. [40].

Table 10 ANOVA for operating parameters affecting specific energy consumption

Source	Sum of squares	df	Mean square	F Value	p-value prob > F	
Model	14771.13	3	4923.71	33.15	< 0.0001	significant
A-CR	12.84	1	12.84	0.086	0.7734	
B-PC	1069.29	1	1069.29	7.2	0.0188	
C-CC	13689	1	13689	92.16	< 0.0001	
Residual	1930.99	13	148.54			
Lack-of-fit	1913.33	11	173.94	19.7	0.0493	significant
Pure Error	17.66	2	8.83			
Cor Total	16702.12	16				

Table 11 Model analysis of operating parameters affecting specific energy consumption

Source	Sequential p-value	Lack-of-fit p-value	Adjusted R-squared	Predicted R-squared	
Linear	< 0.0001	0.0493	0.8577	0.8048	Suggested
2FI	0.8737	0.0385	0.8269	0.6801	
Quadratic	0.1237	0.0522	0.8861	0.5846	
Cubic	0.0826	0.1039	0.9714	0.0719	Aliased

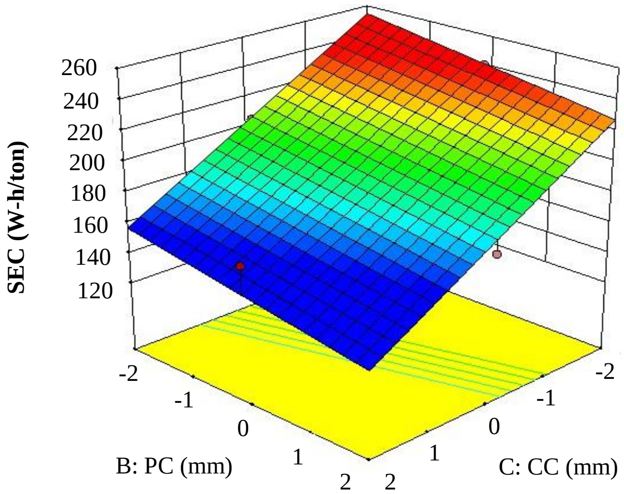


Figure 9 Graph respond surface affected to specific energy consumption of sunflower threshing

3.6 The impact of factor peg-tooth clearance (PC), concave rod clearance (CR), and concave clearance (CC) on grain purity

Analysis of variance (ANOVA) showed the variance analysis on linear regression of grain purity. It was found that peg-tooth clearance (PC) affected grain purity in the axial flow threshing unit at a statistically significant level (p-value < 0.05). Concave clearance (CC) and concave rod clearance (CR) did not affect grain purity in the axial flow threshing unit (p-value > 0.05), as shown in Table 12.

While testing the suitability of the regression (lack-of-fit), a p-value > 0.05 was found indicating that the equation was appropriate for the data [8]. The parameters affecting the efficiency of the axial flow threshing unit can be expressed by Eq. (12).

$$GP = 99.38179 + 0.53375CR + 0.20484PC + 0.043498CC \quad (12)$$

Analysis of variance for threshing efficiency for grain purity in an axial flow threshing unit showed the lowest p-value (p-value < 0.05). This normal linear regression had an adjusted R^2 of 0.5610 and predicted R^2 of 0.3742, as shown in Table 13.

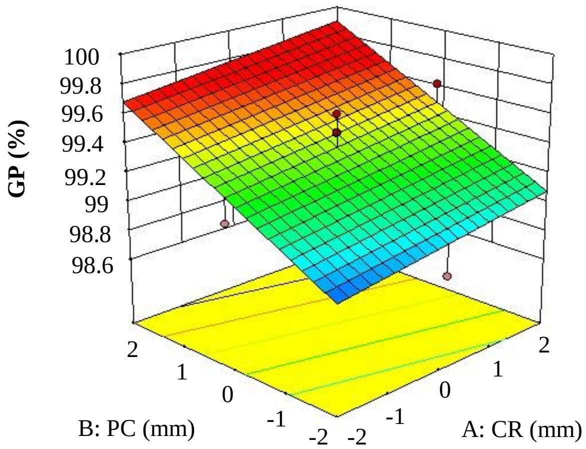
While Eq. (12) is the response surface correlating concave rod clearance (CR), peg-tooth clearance (PC), and concave clearance (CC). This is p-value is less than 0.05, as shown in Figure 10. Increased peg-tooth clearance (PC) improved grain purity in the axial flow threshing unit. Decreased peg-tooth clearance yields higher grain purity with lower grain breakage because the threshing power is reduced. Even if grain purity were increased, it would be disadvantageous for the farmers and the food oil industry because the lower threshing efficiency and high threshing loss cause increased costs in the production process. This is in agreement with the study of Srison et al. [10].

Table 12 ANOVA for operating parameters affecting grain purity

Source	Sum of squares	df	Mean square	F Value	p-value prob > F	
Model	0.75	3	0.25	7.81	0.0031	significant
A-CR	0.046	1	0.046	1.43	0.2531	
B-PC	0.67	1	0.67	21.06	0.0005	
C-CC	0.03	1	0.03	0.95	0.3476	
Residual	0.41	13	0.032			
Lack-of-fit	0.4	11	0.037	6.85	0.1343	not significant
Pure Error	0.011	2	5.36E-03			
Cor Total	1.16	16				

Table 13 Model analysis of operating parameters on grain purity

Source	Sequential p-value	Lack-of-fit p-value	Adjusted R-squared	Predicted R-squared	
Linear	0.0031	0.1343	0.561	0.3742	Suggested
2FI	0.2518	0.1445	0.614	0.1731	
Quadratic	0.2158	0.1651	0.697	-0.0268	
Cubic	0.0489	0.7356	0.9471	0.8318	Aliased



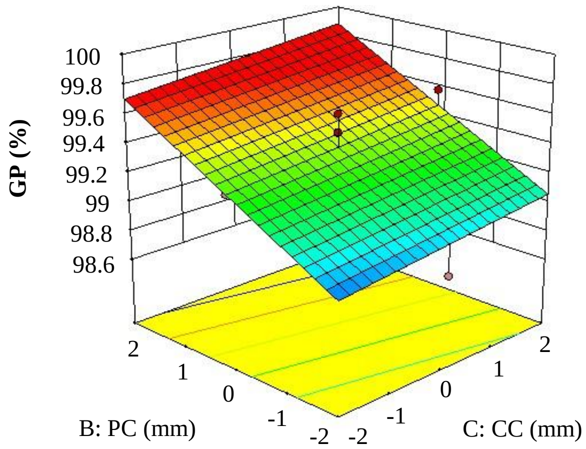


Figure 10 Response surface of grain purity of sunflower threshing for the effects of (a) peg-tooth clearance (PC) and concave rod clearance (CR) (b) peg-tooth clearance (PC) and concave clearance (CC)

4. Conclusions

Several conclusions may be drawn from the current study. They are as follows.

1. The impact of concave rod clearance (CR) is statistically non-significant. This was likely due to increased grain purity as the concave rod clearance decreased, since other-than-grain material could not fall through concave rod clearance.

2. The impact of peg-tooth clearance (PC) was statistically significant for sunflower threshing in terms of percent grain breakage (GB), required threshing power (P) and specific energy consumption (SEC). When peg-tooth clearance is decreased, impact force on the sunflower grains is higher. The impact of concave clearance (CC) was significant in this threshing unit in terms of the threshing loss (TL), threshing efficiency (TE), threshing power (P), and specific energy consumption (SEC). When the concave clearance was decreased, the threshing power (P) and specific energy consumption (SEC) increased.

3. The designed axial flow threshing unit had less than 2% [15] broken grains, less than 2% grain losses [40] and threshing performance greater than 95% [19, 40] at grain sunflower and other-than-grain material sunflower moisture contents of 14.26% and 62.83%. The unit should be operated with concave rod clearance (CR), peg-tooth clearance (PC) and concave clearance (CC) values of 25, 125 and 10 mm, respectively.

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