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Original Article

Effects of operating factors of an axial flow rice combine harvester on grain breakage

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Abstract

The objective of this research was to study the effects of operating factors of an axial flow rice combine harvester on grain breakage, which comprised rotor speed (RS), louver inclination (LI), grain moisture content (MC), feed rate (FR), and grain to material other than grain ratio (GM). The study was conducted on Khao Dok Mali 105 and Chainat 1, which are the two important rice varieties of Thailand. The results of this study indicate that for both of these varieties, the MC and the RS affect the amount of grain breakage. On the contrary, the LI, the FR, and the GM do not have any effect. The MC was found to have a greater impact on grain breakage than the RS of Khao Dok Mali 105, whereas the RS has a greater effect on Chainat 1 grain than the MC.

Keywords: axial flow combine harvester, operating factors, grain breakage

1. Introduction

Rice is very important to economy, society and politics of Thailand. It covers approximately 10.5 million hectares (ha) of cultivated area and yields about 32 million metric tons each year (OAE, 2009). In Thailand, combine harvesters are playing a more important role in harvesting rice and they are widely used in these days. It is estimated that there are about 10,000 rice combine harvester being used (Chinsuwan, 2010). Most of them are Thai-designed rice combine harvesters (Figure 1) and all have an axial flow threshing unit.

The threshing unit is a very important component of an axial flow combine harvester. The use of threshers can affect the grain quality as they may cause breakages. Broken grain means that organisms can easily penetrate the broken grains so that breakage can lead to difficulties in the storage of the grain, a factor affecting grain quality. A study by Chinsuwan *et al.* (2003) of an axial flow rice combine harvester shows that an increase of the rotor speed increases the amount of grain breakage, while the feed rate does not have any effect on grain quality. Gummert *et al.* (1992) who conducted a study on an axial flow rice combine harvester also found that the rotor speed affected the amount of grain breakage, but the feed rate and louver inclination do not cause any breakage to grain. A study on the rotor speeds operating on wheat and its moisture grain content (Joshi and Singh, 1980) shows similar results, i.e., the greater the rotor speed,

Figure 1. Thai-designed rice combine harvester under study.

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the greater the amount of grain breakage. At the same time, this study indicates that increased grain moisture content decreased grain breakage.

Combine harvesters involve a number of important operating factors that lead to loss from the threshing unit, namely, rotor speed, louver inclination, feed rate, grain moisture content and grain to material other than grain ratio (Chuan-Udom and Chinsuwan, 2009). These factors may be the cause of grain breakage. The above problems make it necessary to study the operation of the threshing unit of a combine harvester in order to reduce grain breakage. This research was therefore aimed at studying the effects of the operation of an axial flow combine harvester on grain.

2. Methodology

2.1 Equipment

The equipment used in this study was a Thai axial flow rice combine harvester with a threshing rotor length of 1.92 m and a diameter (to peg tip) of 0.68 m. Each peg was 11 mm in diameter and 82 mm long, and the space between pegs was 70 mm. The concave rods were 7 mm in diameter with a 17 mm clearance between each rod. There were 5 louvers, and the combine harvester cutting width was 3 m. The engine power was 194 kw (260 hp).

2.2 Experimental factors

There were five independent variables considered in developing equations for grain breakage (GB): rotor tangential speed (RS), louver inclination (LI), grain moisture content (MC), feed rate (FR), and grain to material other than grain ratio (GM). For the test the RS values were 15.78, 16.50, 17.22, 17.93, 18.65, and 19.37 m/s. The LI (Figure 2) settings were 64, 66, 68, 70, 72, and 74 degrees. The MC depended on crop conditions during the test. The FR and grain and material other than grain through the threshing unit varied with 3 forward speeds of 3, 4, and 5 km/h. The GM varied with the cutting height, which was set at 3 levels, low, medium, and high (average 332, 424, and 487 mm, respectively). The two rice varieties used in this study were Khoa

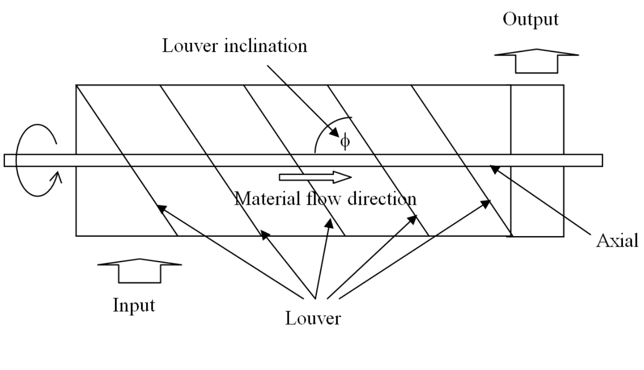

Figure 2. Louver inclination, top view.

Dok Mali 105, which is the most famous local variety and Chainat 1, which is an important hybrid variety in Thailand.

To help in managing these tests, the five variables were simplified by setting the LI at a fixed value for each testing day during the testing period of 10 days. The MC depended on the conditions of the plot of the day. There were three plots harvested on each day of testing, while the RS, the forward speed and the cutting height were varied alternately each day. The FR depended on the forward speed, cutting height, cutting width, and crop conditions, and the GM depended on the cutting height and crop conditions. The effects of the threshing unit operating factors on the amount of grain breakage are shown in Table 1 for Khoa Dok Mali 105 and Table 2 for Chainat 1.

2.3 Measurements

In the test, five kg of grain sample flowing out from the threshing unit outlet was left to dry and cleaned thereafter. Then the grain breakage was found by sorting the grain. It is stated as the weight percentage of broken grain to the total sample.

2.4 Determination of threshing unit operating factors affecting grain breakage

The LI, MC, RS, FR, and GM values in Table 1 were used to be the GB for the combine harvester by applying the general model for a quadratic response surface, as shown in Equation 1. This model demonstrated the relationships of a number of parameters, which are shown in linear, second degree, and interaction patterns (Berger and Maurer, 2002). A regression model was developed and any model term that had a very small effect on a dependent variable was eliminated. Next, the regression model was reformulated without the eliminated term. Thus, the term in the regression model that had the least effect on the dependent variable was eliminated and a new regression model was produced as long as the validity value of the final model terms was not lower than 95%.

$$Y = A_0 + {}_{(j=1,k)} A_j X_j + S_{(j=1,k)} A_{jj} X_j^2 + S_{(j=1,k-1)} S_{(i=j+1,k)} A_{ij} X_i X_j \quad (1)$$

where Y = dependent variable

X_i, X_j = independent variable

A_0, A_j, A_{jj}, A_{ij} = constant

j = 1, 2, 3, … , k ; (for k factors)

i = $j + 1$

From the obtained parameters, the terms affecting the amount of grain breakage were used in the construction of regression equations. Then the equations were applied in analyzing the effects of parameters on the amount of grain breakage based on the best subset regression method, determining the effect of each parameter on R^2 (Draper and Smith, 1998.) by using SPSS Statistics 17.0 Release, SN: 5068054.

Table 1. Effects of threshing unit operating factors on the amount of grain breakage of Khao Dok Mali 105.

LI degree	MC %-wb	RS m/s	FR t/h	GM	GB_H %
		15.78	7.98	0.83	0.018
68	27.40	17.22	9.10	1.05	0.050
		18.65	10.81	1.38	0.022
		16.50	11.58	0.78	0.015
72	26.51	17.93	9.01	1.04	0.045
		19.37	7.60	1.12	0.027
		15.78	8.71	1.23	0.014
70	25.10	17.22	6.14	1.53	0.043
		18.65	10.09	0.95	0.070
		16.50	10.46	0.97	0.006
64	24.31	17.93	11.97	1.16	0.041
		19.37	9.68	0.81	0.049
		15.78	7.06	1.40	0.009
74	24.55	17.22	10.61	1.04	0.018
		18.65	5.87	1.32	0.120
		15.78	7.00	0.86	0.020
66	23.63	17.22	8.84	0.72	0.061
		18.65	10.17	0.87	0.194
		16.50	7.13	1.06	0.011
68	25.66	17.93	12.23	0.75	0.033
		19.37	13.27	1.00	0.093
		16.50	5.80	0.95	0.068
70	22.73	17.93	8.18	1.19	0.155
		19.37	11.30	0.86	0.246
		15.78	6.09	0.79	0.062
66	20.46	17.22	7.53	0.42	0.091
		18.65	6.12	0.58	0.267
		16.50	12.75	0.30	0.043
72	17.35	17.93	6.40	0.45	0.201
		19.37	7.39	0.47	0.820

Table 2. Effects of threshing unit operating factors on the amount of grain breakage of Chainat 1.

LI degree	MC %-wb	RS m/s	FR t/h	GM	GB %
		15.78	9.65	0.68	0.011
68	27.72	17.22	11.37	0.94	0.039
		18.65	10.64	1.66	0.118
		16.50	18.47	0.61	0.091
72	23.54	17.93	8.66	1.14	0.129
		19.37	7.96	1.38	0.199
		15.78	14.08	1.21	0.032
70	25.54	17.22	7.61	1.51	0.046
		18.65	17.28	0.67	0.089
		16.50	11.50	0.73	0.023
64	26.56	17.93	11.08	1.10	0.019
		19.37	13.34	0.34	0.076
		15.78	5.11	1.05	0.076
74	23.42	17.22	12.12	0.60	0.040
		18.65	6.56	0.96	0.266
		16.50	6.42	1.54	0.065
66	23.35	17.93	13.77	0.71	0.075
		19.37	13.06	1.25	0.524
		15.78	10.17	1.45	0.088
68	23.40	17.22	11.35	0.55	0.055
		18.65	11.82	1.01	0.163
		16.50	11.78	0.61	0.042
70	21.35	17.93	12.14	0.81	0.154
		19.37	11.47	1.12	0.334
		15.78	14.43	0.54	0.025
66	23.89	17.22	11.56	0.97	0.054
		18.65	6.91	1.47	0.203
		16.50	11.14	0.34	0.061
72	19.59	17.93	10.26	0.61	0.183
		19.37	10.23	0.93	0.392

3. Results and Discussion

Table 1 depicts the results of the study conducted on Khao Dok Mali 105. The louver inclination values used were in the range of 66 to 74 degrees. The grain moisture contents (MC) were from 16.94 to 27.79 %-wb. The rotor speeds (RS) ranged from 15.78 to19.37 m/s. The feed rates (FR) were from 5.80 to 13.27 tons/h and the grain to material other than grain ratios were from 0.30 to 1.53. The grain breakage (GB) was found to be from 0.006 to 0.820 percent.

For Chainat 1 hybrid variety, the louver inclinations were also from 66 to 74 degrees. The moisture contents (MC) ranged from 19.42 to 27.79 %-wb. The rotor speeds (RS) were from 5.78 to 19.37 m/sec. The feed rates (FR) were from 5.11 to 18.47 tons/h, and the grain to material other than grain ratios were from 0.34 to 1.66. The amount of grain breakage (GB) found was from 0.011 to 0.392 percent, as shown in Table 2.

3.1 Operating parameters affecting the amount of grain breakage

Table 3 shows that the operating parameters, namely the rotor speed (RS), grain moisture content (MC), and multiples of the rotor speed and moisture content (CS×MC) affected the amount of grain breakage both in the case of

Table 3. Operating factors affecting the amount of grain breakage.

Khao Dok Mali 105		Chainat 1	
Terms	Reliability (%)	Terms	Reliability (%)
CS	99.9	CS	99.7
MC	99.9	MC	97.9
CS×MC	99.9	CS×MC	98.8

Khao Dok Mali 105 and Chainat. The lover inclination, feed rate, and grain to material other than grain ratio did not have any effect on grain breakage at the reliability level of 95 percent.

3.2 Estimating equations for grain breakage from operating parameters

The parameters affecting grain breakage could be taken to build estimating equations for grain breakage. Equation 2 is for the estimation of Khoa Dok Mali 105 grain breakage (GB_H) and Equation 3 is for Chainat 1 variety (GB_C). The coefficients of decision (R^2) are 0.85 and 0.70, respectively.

$$GB_H = -10.36 + 0.63(CS) + 0.40(MC) - 0.024(CS \times MC) \quad (2)$$

$$GB_C = -5.90 + 0.37(CS) + 0.21(MC) - 0.013(CS \times MC) \quad (3)$$

From the grain breakage estimating Equation 2 and 3, the percentages of the effects of rotor speed and grain moisture content on the amount of grain breakage were analyzed (Figure 3). It was found that for Khao Dok Mali 105 the rotor speed and grain moisture content affected the amount of grain breakage at 44.6% and 55.4 %, respectively. The grain moisture content affected the grain more than the rotor speed. This was different from the case of Chainat 1 variety, in which the rotor speed had a greater effect on the amount of grain breakage than the grain moisture content, at 70.6% and 29.4%, respectively. This was because Khao Dok Mali, an indigenous variety, is more prone to breakage, when its moisture content varies, than Chainat 1, which is a hybrid variety.

3.3 The effects of operating factors on the amount of grain breakage

From Equation 2, the relationships between the rotor speed and grain moisture content affecting grain quality of Khao Dok Mali 105 could be analyzed as shown in Figure 4. It was found that when the rotor speed was less than 16 m/sec in the grain moisture content range of 18 to 28 %-wb, the amount of grain breakage was insignificant. However, when the speed was higher than 16 m/sec, grain breakage increased rapidly, especially when the moisture content was low. On the contrary, when the grain moisture content was higher than 26 %-wb and the rotor speed was between 15 and 20 m/sec, grain breakage was little. This could happen because the grain with moisture content higher than 26 %-wb was still not fully mature. The grain was still not solid and had high flexibility when the thresher bet on it; hence, breakage of the grain was little. The grain with moisture content lower than 26 %-wb was more mature and harder, while its flexibility became lower; therefore, the grain was more prone to breakage when was beaten, especially in the case of dry grain or grain with low moisture content. The rotor speed affected the amount of grain breakage when it was increased so that the threshing action was harder resulting in greater grain breakage (Chinsuwan *et al.*, 2003).

For Chainat 1 variety, when Equation 3 was used to build the relationships between the rotor speed and the grain moisture content affecting the amount of grain breakage as shown in Figure 5, it was found that if the speed of the rotor was not over 16 m/sec in the range of grain moisture content of 18 to 28 %-wb, the grain was not significantly broken. When the rotor speed was increased over 16 m/sec, the amount of breakage increased rapidly, especially when the moisture content was low, as in the case of Khao Dok Mali 105. However, if the grain moisture content was higher than 27 %wb, and the rotor speed was in the range of 15 to 20 m/sec, breakage of grain was very little.

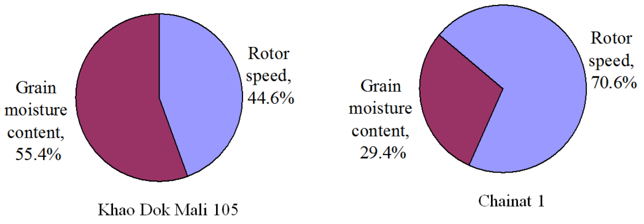

Figure 3. Percentage of the effects of rotor speed and grain moisture content on the amount of grain breakage.

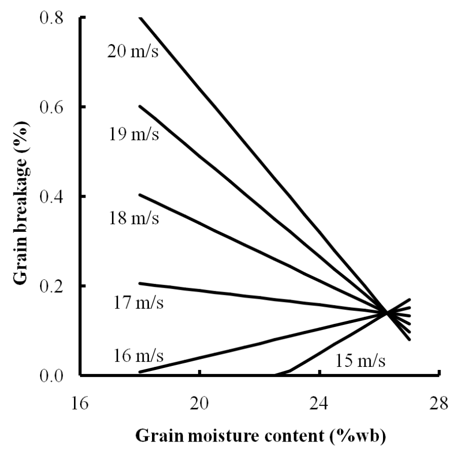

Figure 4. Effects of rotor speed and grain moisture content on grain breakage in Khao Dok Mali 105 variety.

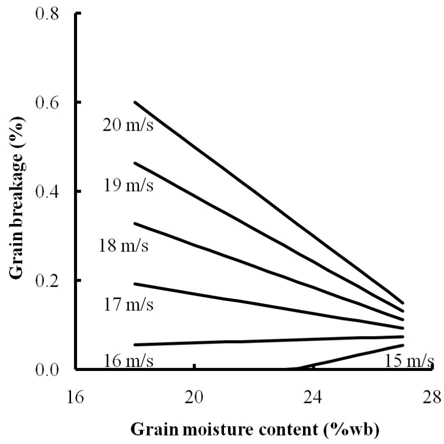

Figure 5. Eeffects of rotor speed and grain moisture content on grain breakage in Chainat 1 variety.

From the estimating equations for grain breakage of the two rice varieties, we found that the rotor speed and grain moisture content had a greater effect on the amount of grain breakage for Khao Dok Mali 105 than Chainat 1. This might be because the former is less flexible than the latter. From these equations it can be concluded, that if the amount of breakage is required to be lower than 0.5 percent, like for Khao Dok Mali 105, harvesting should be done when the grain has a moisture content not less than 20 %-wb and the rotor speed should not exceed 19 m/sec. Chainat 1 should be harvested when its grain moisture content is not less than 20 %-wb and the applied rotor speed should not higher than 20 m/sec.

4. Conclusions

For an axial flow combine harvester, the grain moisture content and rotor speed have been found to affect the amount of grain breakage both for Khao Dok Mali 105 and Chainat 1 varieties. The louver inclination, feed rate, and grain to material other than grain ratio have insignificant effects on grain qualities. For Khao Dok Mali 105, the rotor speed and grain moisture content affect the amount of grain breakage at 44.6 and 55.4%, respectively, whereas for Chainat 1, the rotor speed and grain moisture content affect grain qualities at 70.6 and 29.4%, respectively. In operating the combine harvester, if breakage has to be kept lower that 0.5%, the rotor speed should not exceed 19 m/sec and harvesting should be done when the grain moisture content is not less than 20 %-wb.

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