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Analysis of the Cutting Shape as a Function of Feed Rate and Cutting Speed of Korean and Japanese Combines

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Abstract

Purpose: In this study, we attempted to analyze, by using a high-speed camera, the cutting shape as a function of cutting speed and feed rate. We compared the differences in cutting shape between domestic and foreign combines. **Methods:** Experiments were performed using plastic straws, and the results of two combine cutting blades, one from the Daedong Industry and one from Kuboda, were compared. The quality and performances of cutting were measured at three cutting positions: center and 68 cm to the left and right of the center. The feed rates were 0.6 m/s, 1.1 m/s, 1.6 m/s, and the cutting speeds were 600 RPM, 990 RPM, 1,380 RPM. For each speed, the cutting shape was measured three times, and the entire procedure was also repeated three times. **Results:** In the experiments, the domestic cutting blade achieved better results than the Japanese cutting blade. These results were obtained by studying the combination of feed rate and cutting speed, with the domestic combine attaining approximately 80% performance of the Japanese combine. We believe that additional data analysis is required, obtained from field experiments. **Conclusions:** The domestic cutting knives achieved better results than the Japanese cutting knives. These results are estimated from experiments conducted with different feed rates and cutting speeds; an in-depth analysis will require experiments in the real field with actual combines and a combination of multiple variables. Repeating the investigation on the length differences, broken and cut angle with various combinations of feed rate and cutting speed, will surely help to find the optimal cutting speed.

Keywords: Combine, Cutting knife, Cutting speed, Feed rate, Rice straw

Introduction

The transition of Korean agriculture from a domestic to a large-scale and mechanized one is increasing the use of agricultural machinery and the related parts. One of such machinery is the binder or combine cutting knife, which is composed of triangular shaped blades riveted to a knife bar. The cutting blade is an indispensable component of combines and has many uses. Currently, the cutting blades and other parts of the combine are mostly produced by foreign companies and account for half the imports of agricultural machinery (Kim et al., 2006). It is then necessary to locally manufacture these components. Domestic cutting blades are made of carbon steel (SK5), whose surface is hardened by a high-frequency heat treatment (Jeon et al., 2002), which can easily produce a deformation of the knife. Deterioration of the cutting performance is also a common problem with the domestic blades (Chung et al., 1995; Lee et al., 1995) and especially the breaking of blades affects the domestic knives and forces many farmers to import expensive cutting blades from Japan (Choi et al., 2004). The reason of the breaking is attributed to the mismatch of cutting speed and feed ratio in the domestic combines. In this study, attempts have been made to identify the dependence of the cutting shape on the cutting speed and the feed rate by means of a high-speed camera. The differences in the cutting shape of both the domestic and foreign combines were also compared.

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Materials and Methods

A transfer device made in-house and the actual combine's cutting device have been used in order to identify the cutting shapes. The actual feed rate was matched with the rate of the in-house transfer device that can be adjusted from 0-0.33 m/s. Three transfer ports were also mounted on the transport device so that three crops could be cut simultaneously (Figure 1, 2). After removing all the unnecessary parts, the cutting device of the combine was mounted on a fixed frame, and the experiments were conducted indoor to allow the use of a high-speed camera (Table 1) that captured the movement of the cutting blades. The cutting device was driven by a motor through a belt drive, and a tachometer was connected to the blade in order to measure and adjust the cutting speed. Plastic straws were used as cutting samples, as previous studies from our group demonstrated that the cutting force required for plastic straws is similar to that of rice stems. Moreover, paddy was not available at the time of the experiments. The change of cut crop features for different experimental variables was confirmed by the high-speed camera (Figure 3). After the experiment, the cut shape was measured and quantitatively expressed.

Commercially available plastic straws (diameter 0.6 cm) were used in the experiment. The comparison was between the cutting performances of a Daedong Industry combine's cutting knife and a Kuboda combine's cutting knife (Figure 4). The experimental parameters are listed in Table 2, and the cutting performances have been measured at three positions (center, left and right) spaced by 68 cm (Figure 5). The feed rates used in the experiments were 0.6 m/s, 1.1 m/s, 1.6 m/s and the cutting speeds were 600 RPM, 990 RPM, 1380 RPM. For each cutting speed, the cut shapes were measured three times.

The shape of the cut straw, the cutting angle, the number of broken straws were quantified by summing the results of three measurements. We measured the

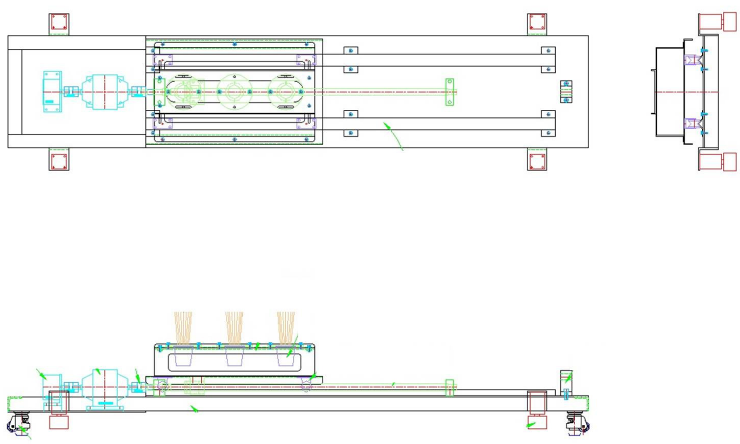

Figure 1. Drawings of the transfer device used in the experiments.

Figure 2. Pictures of the transfer device and its controller.

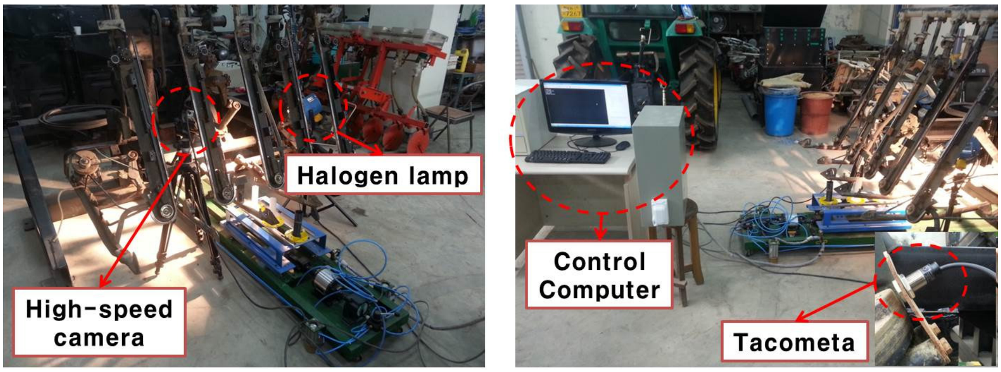

Figure 3. Experimental setup.

Table 1. High-speed camera specifications

Parameter	Value
Lens mount	C mount
Imaging sensor	Progressive scan 1/3-inch CCD, square pixels
Framing rate	Full frame : 30, 60, 125, 250 fps Partial frame : 500, 1000 fps
Pixel resolution	Full frame : 512×480 pixels Partial frame : 512×240; 256×240; 256×120 pixels 128×120; 128×80; 128×34 pixels
Dimensions	Camera head: 160W×300D×180H mm PCI board: 312W×106H×16T mm

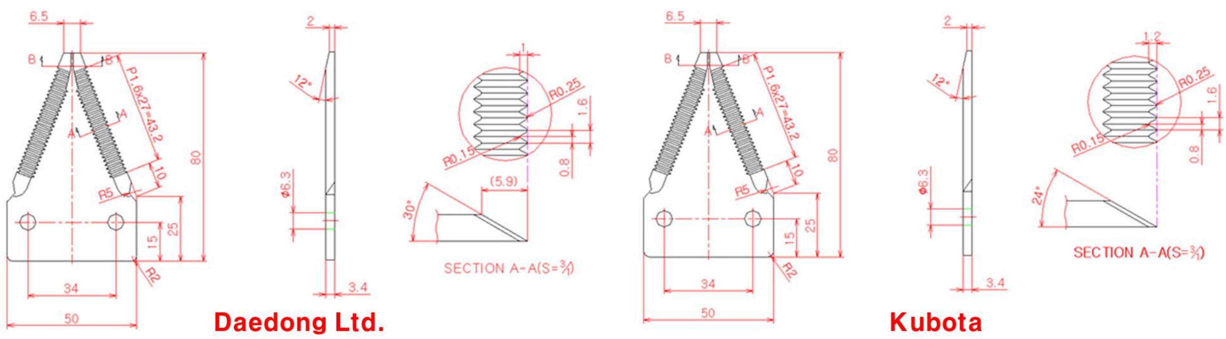

Figure 4. Cutting knives design.

Table 2. Experimental configuration

Parameter	Cutting knife (kgf)
Cutting speed	600, 900, 1380 rpm
Conveying speed	0.6, 1.1, 1.6 m/s
Test positions	Cutting knife on the left, right and center
Number of tests	3×3×3×3=81×3 repeat=243
Cutting target	Plastic straw

Figure 5. Test positions on the blade (Left, Center, Right).

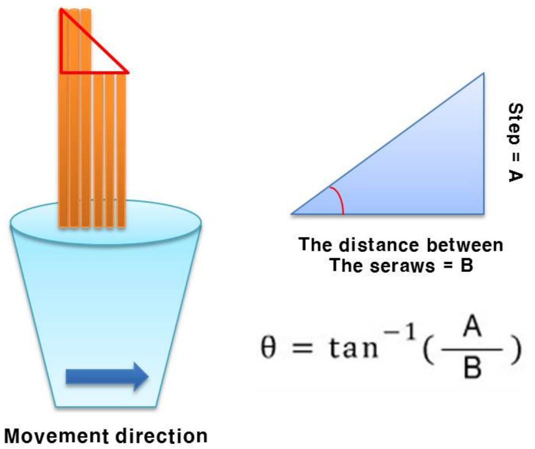

Figure 6. Method for quantification of cutting quality.

longest and the shortest straw and their difference, in order to obtain the angle shown in Figure 6. The number of truncated and broken straws was counted to quantify the cutting shape. Because the average number of stems measured in the paddy was 35 for one blade, for the experiments, 35 straws were tied with rubber bands and fixed to paper cups by paraffin.

Results and Discussion

In previous experiments, the measurement of the cut shape on the paddy was complex and it did not yield well-defined results. In order to overcome this problem, we measured the cut shape on plastics straws, (Figure 7) that maintain their characteristics after the cutting. The experiments showed that most of the cutting occurs at about one-third of the blade, but if the cutting speed is increased a substantial portion of cut occurs instead at the beginning of the blade. If the feed rate is increased, the straws are cut at the middle of the blade, but the cut is not clean. Further experiments and an analysis of biting (i.e., straws that are hit by the blade but not cut) suggest that it is possible to find a correlation between feed rate and cutting speed that yields the optimal cutting shape.

Figure 8 shows the height differences (steps) among the cut straws, as a function of the cutting speed. It can be seen that the size of steps increases as the cutting speed is lowered. The number of cutting times occur that the target of unnecessary force and cutting blade can be interpreted a lot of load. The steps did not change significantly with the feed rate as happens for cutting speed.

Figure 7. Straws before and after cutting.

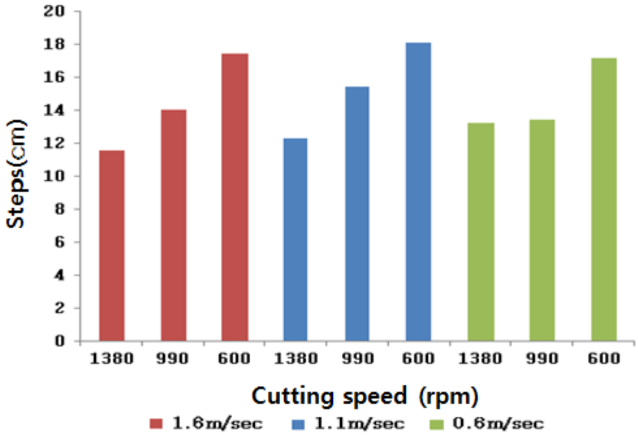

Figure 8. Variation of steps (height differences) with cutting speed (Daedong Ltd. combine).

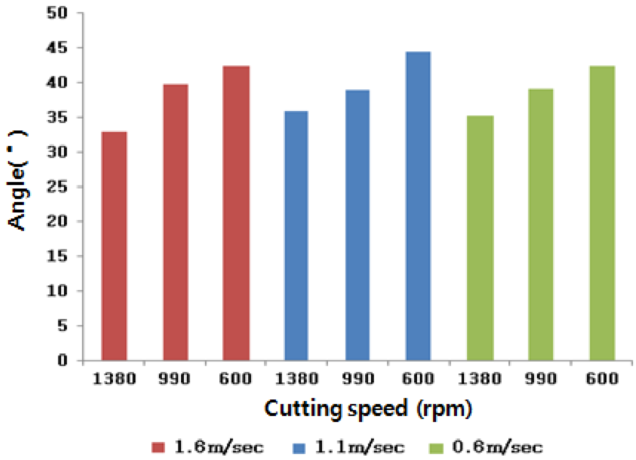

Figure 9. Variation of angle with the cutting speed. (Daedong Ltd. combine).

Figure 9 shows that the angle increases (and the straws are cut several times) as the cutting speed is decreased. This behavior is similar to that of the steps.

Figure 10 shows the number of broken straws as a function of cutting speed for the Daedong Industrial combine. The number of broken straws decreases as the cutting speed is lowered for 1300 rpm and 990 rpm, but

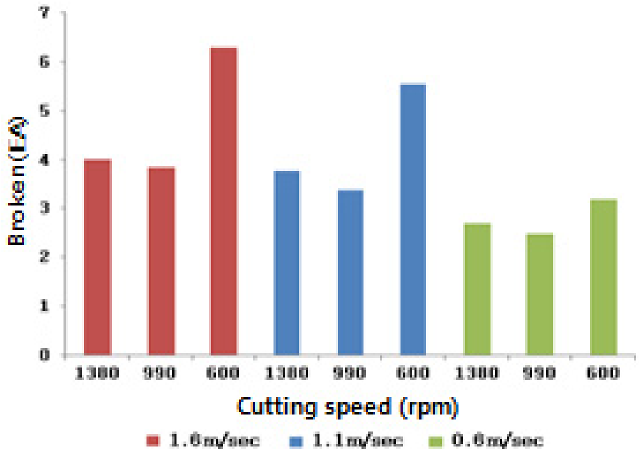

Figure 10. Variation of the number of broken straw with the cutting speed. (Daedong Ltd. combine)

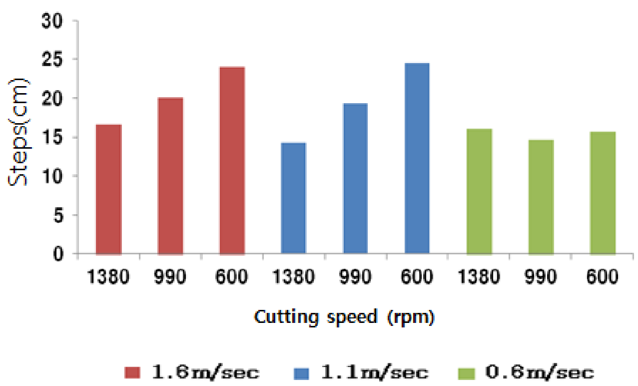

Figure 11. Variation of steps with the cutting speed. (Kubota combine)

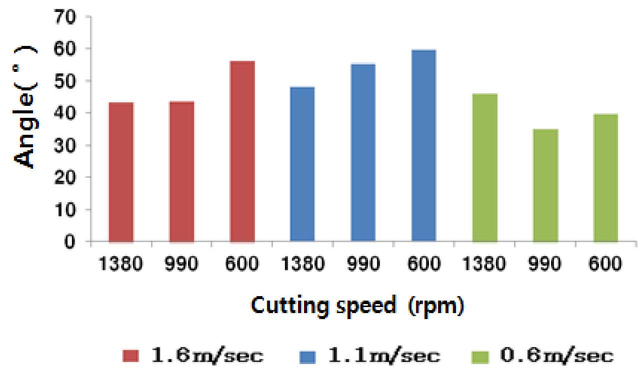

Figure 12. Variation of angle with cutting speed. (Kubota combine)

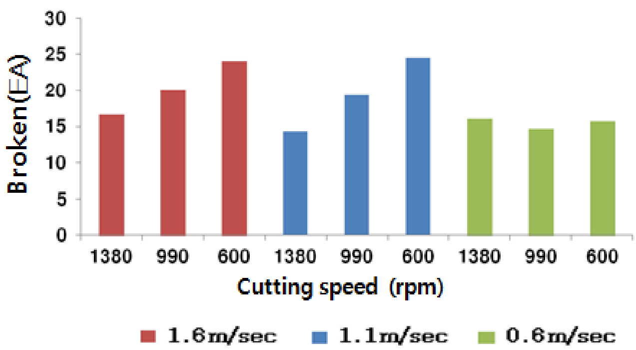

Figure 13. Variation of the number of broken straws with the cutting speed, (Kubota combine)

it sharply increases at 600 rpm. The reason is that when the cutting speed is lowered, the straws remain in contact with the blade for a longer time, increasing the probability of being cut. But when the cutting speed is reduced below a certain limit, a mismatch appears between cutting speed and feed rate resulting in more broken straws. By lowering the feed rate, a slight decrease in broken straws is found.

Figure 11 shows the steps as a function of cutting speed for the Kubota combine, for feed rates of 1.6 m/s, 1.1 m/s and 0.6 m/s. It can be seen that the steps increase as the cutting speed is reduced, but the smallest steps were obtained for a feed rate of 0.6 m/s and a cutting speed of 990 rpm. This combination of speed and rate appears to be the optimal solution for reducing the steps. In future studies, we will investigate the feed rates of 1.6 m/s and 1.1 m/s, in order to find the corresponding optimal cutting speed that result in the lowest step.

Figure 12 shows variations in cutting angle with the cutting speed for the Kubota combine. The dependence of the cutting angle on the cutting speed is similar to the steps shown in Figure 11. For feed rates of 1.6 m/s and 1.1 m/s, the cutting angle increases as the cutting speed is lowered. The smallest cutting angle was obtained for a speed of 990 rpm and a feed rate of 0.6 m/s. In future experiments, the feed rates of 1.6 m/s and 1.1 m/s will be analyzed in detail, with the aim to find the appropriate cutting speed which yields the smallest cutting angle.

Figure 13 shows the number of broken straws as a function of the cutting speed for the Kubota combine; the observed dependence is similar to those of cutting angle and steps. For transfer rates of 1.6 m/s and 1.1 m/s, the number of broken straws increases as the cutting speed is decreased; the optimal configuration with the minimum number of broken straws was found for a feed rate of 0.6 m/s and a cutting speed of 990 rpm.

The results of the experiment indicated that the domestic cutting knives showed better results than the Japanese cutting knives. These results are displayed via variables with only the simple feed rate and cutting speed and it is judged that results different from the actual combine performance are displayed. According to the performance evaluation materials released from each manufacturer, domestic combine shows work efficiency of about 80% compared with Japan Combine, so additional experiments are necessary to investigate accurate performance difference It will be judged. We believe that additional analysis will be necessary, with data obtained from actual field application, in order to investigate the differences between domestic and imported combines. These result will be useful for improving the performances of domestic combines.

Conclusions

We compared, by means of a high-speed camera, the cut shape and quality produced by a Korean and a Japanese combine, as a function of feed rate and cutting speed. We studied the cut quality for a combination of the variables cutting speed and feed rate, and our results showed that the domestic cutting knife attained overall better results than the Japanese one. In future experiments, we intend to test the actual combine on real fields for different operating variables. A review of the cutting level differences, broken straws and cut angle would help to find the optimal combination of cutting speed and feed rate.

Conflict of Interest

The authors have no conflicting financial or other interests.

Acknowledgments

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References

Choi, W. Y. and T. H. Kim. 2004. An effect of the shape of cutting blaed on cutting resistance of rice stalk. Agricultural research bulletin of Kyungpook Univ. 22:41-48.

Chung, C. J., S. B., Lee and H. S. In. 1995. Cutting-pattern and cutting characteristics of the reciprocating cutter-bar of combine harvester(I) - Cutting mechanism and cutting characteristics of the standard type reciprocating knife -. Journal of the Korean Society for Agricultural Machinery 20(1):3-12.

Jeon, J. G., G. W. Kim, J. H. Yun, H. G. Cho, I. B. Lee and H. S. Seong. 2002. Analysis on the characteristics of combine cutters heated by a high frequency induction heater through field test. Journal of Biosystems Engineering 2002:27-32.

Jeon, J. G, G. W. Kim, J. H. Yun, H. G. Cho and I. B. Lee. 2002. Analysis on the characteristics of combine cutters heated by a high frequency induction heater. Journal of Biosystems Engineering 2002:523-528.

Kim J. H., C. H. Choi, Y. J. Kim, E. H. Nam and J. H. Mun. 2006. Development of measurement system for combine header diagnoses. Journal of Biosystems Engineering 11(1):98-103.

Lee H. J., H. Y. Kim, J. H. Hong and S. B. Lee. 1995. Cutting-pattern and cutting characteristics of the reciprocating cutter-bar of combine harvester(ii) - Cutting characteristics of the low-cutting type and double cutting type reciprocating knives -. Journal of the Korean Society for Agricultural Machinery 20(1): 13-21.