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Sorghum Harvesting Using a Head-feeding Type Rice Combine

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Abstract

Purpose: The aim of this study was to determine appropriate threshing and selection conditions for sorghum harvesting using a rice combine-harvester. **Methods:** Sorghum harvesting performance was tested using an actual rice combine. Through this test, the grain loss rate and the composition of crops according to the engine and fan speeds of the combine were investigated. Furthermore, the optimal threshing and selection conditions were determined by carrying out a harvest test based on the opening size factor of the concave in a test field. **Results:** The grain loss rate for the sorghum using a concave (18×18 mm) of the rice combine was the lowest at 0.1% at a chaffer angle of 40°, engine speed of 2000 rpm, and fan speed of 20 m/s, but the sorting sieve clogged frequently. Furthermore, as the engine speed and fan speed increased, the grain loss rate also increased. The sorghum harvesting test results of the combine according to the concave opening size showed that the grain loss rate was 0.5% at a driving speed of 0.5 m/s, with a concave opening diameter of 13 mm, a chaffer angle of 40°, a concave sieve oscillation frequency of 4.8 Hz, a fan speed of 20 m/s, and an engine speed of 2000 rpm. **Conclusions:** Findings showed that sorghum could be harvested using a head feeding rice combine.

Keywords: Cleaning, Combine harvesters, Concaves, Sorghums, Threshing

Introduction

Sorghum is one of the cereal crops grown in Korea (about 1,547 ha) (KOSIS, 2009). Harvesting of sorghum is usually not mechanized and is done manually, which requires more labor input. Lately, sorghum is becoming known as a food material with increasing consumption, but is mostly available in Korea through imports.

Agricultural labor in rural areas of Korea is minimal, which increases labor costs and makes it difficult to obtain the labor required during harvest time. To solve this problem, mechanized harvesting of sorghum is required.

In Korea, rice cultivation is common, and the combines used for rice harvesting are readily available in large numbers. Rice combines are expensive and are only used in the rice harvesting season. Thus, they have low utilization efficiency and economic efficiency due to the short usage period. If they could be used for harvesting crops other than rice, the utilization efficiency of the rice combines could be increased.

Masane et al. (2016) reported the physical properties of tender sorghum (*Sorghum bicolor* L.) grain and Nattapol et al. (2014) reported the effect of moisture content on the physical and aerodynamic properties of sorghum. Jun et al. (2015) reported that millet harvesting was possible through the improved performance of a head-feeding rice combine to harvest foxtail millet. Sorghum is different from rice in terms of crop height and crop shape, but a head-feeding-type rice combine is adaptable for sorghum harvesting. However, sorghum harvesting using a rice combine generates large grain loss and the sieve is clogged frequently due to poor sorting. If these problems are solved, sorghum harvesting

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using rice combines will increase. Therefore, we attempted to solve the problems of sorghum harvesting by investigating the concave structure, mesh size, and shape of the rice combine threshing parts.

Using rice combines to harvest sorghum means that labor input could be reduced and that the usage rate of the combines could be enhanced (Jun et al., 2014). Thus, a study on the mechanical harvesting of sorghum through threshing and selection of sorghum in advance is deemed necessary. A head of sorghum usually separates into individual grains while threshing because the head of sorghum consists of a cluster of grains. There is little grain loss during the cleaning process because the threshed sorghum is easy to separate into grains. Therefore, this study was conducted to investigate the threshing, separation, and cleaning of the sorghum.

Materials and Methods

Properties of the sorghum for the experiment

Crop properties of each sample were investigated for experimental samples of sorghum I (Sodamchal, short plant) and sorghum II (Nampungchal, tall plant). Table 1 lists the properties of the sorghum samples while Figure 1 shows the shape of the sorghum crop.

Experiment 1: Grain loss test for pure grains at the cleaning sieve of the combine

A threshing test of the sorghum was conducted using a rice combine (Model-DSM70) during threshing, separating, and cleaning. Table 2 shows the parameters of the rice combine. In the sorghum separation test, the threshed parts were separated and the conditions of the frequency of the cleaning sieve, the chaffer angle, and rotating speed of the fan were changed for the experiment using the rice combine. Table 3 shows the experimental conditions for measurement of the grain loss of the sorghum at the separation part and cleaning sieve of the rice combine. To decrease grain loss and improve the quality of the harvested grain, it is important to consider the factors of threshing, separation, and cleaning, which include the threshing concave, sieve frequency, chaffer angle, and air velocity. As shown in Table 3 and Figure 4, the combine has three fan speeds that can be adjusted via the fan lever position. The frequency of the cleaning sieve (shoe) works in proportion to the engine speed.

The speed of the threshing drum of the combine harvester was kept at almost maximum 500 RPM, which is the proper speed of the threshing drum of a combine harvester for rice (Tarui, 1962).

The working speed for the experiment conducted in the field was set at all three levels. For an engine speed of 2,000 RPM, the combine can barely operate at the working speed of 0.5 m/s. The engine can reach a maximum of 3,000 RPM. The mesh concave of the rice combine has an opening size of 18×18 mm. Generally, a grain of rice is not heavier than barley and wheat. Nevertheless, rice straw is tougher than barley and wheat straw (Jun et al., 2015). The chaffer angle of a rice combine was set at 35° for rice and 45° for barley. Therefore, the chaffer angle of the cleaning sieve for the sorghum harvesting experiment was set at two levels of 40° and 55° to delay the time required for the sorghum stems to go through the chaffer sieve for separation, as shown in Figure 5. This is because

Table 1. Properties of the sorghum used in the experiments

Variety	Total height (m)	Length / Diameter of sorghum head (mm)	Diameter of grain (mm)	Weight (g/1,000 grains)	Moisture of sorghum head (%, d.b.)
Sorghum I (Sodamchal)	1.09±0.07	230/70	3.6	25.7	69.7
Sorghum II (Nampungchal)	1.58±0.21	170/60	3.3	22.8	69.7

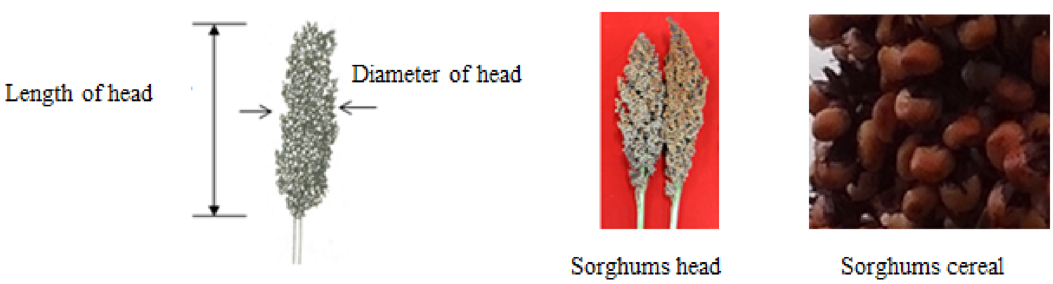

Figure 1. Shape of a sorghum head and grains.

Figure 2. View of the rice combine (DSM70).

Table 2. Parameters of the rice combine (DSM70)

Parameters of the rice combine		Value
Engine	Power/Speed (kW/RPM)	48 / 2,700
Threshing part	RPM of drum (rpm)	505
	Diameter of drum (mm)	550
	Length of threshing drum (mm)	900
	Opening size of concave (mm)	18 x 18
Fan	Length of fan (mm)	690
	Fan speed (3 speeds) (RPM)	755 - 1,620
	Number of fan wings	4
	Diameter of fan (mm)	340
Separation and cleaning part	Adjusting chaffer angle of cleaning shoe (°)	25 - 55
	Length and width of cleaning shoe (mm)	665 x 1,550
	Frequency of cleaning shoe (HZ)	4.8 - 7.2
	Amplitude of cleaning shoe (mm)	20
Cutting part	Cutting height (mm)	35 - 150
	Adaptable height of crop (mm)	550 - 1,300
	Cutting width (mm)	1,450 - 1,500

Table 3. Experimental condition for the grain loss measurement at the cleaning sieve of the combine

Parameters	Contents
Variety of sorghum	Sorghum I (Sodamchal)
Weight of sample (g / time)	100 g (grain)
Frequency of cleaning shoe (Hz)	Three levels (4.8, 6.1, 7.2)
Position of fan adjustable lever	Three speeds (High, Middle, Low)
Chaffer angle of the sieve (°)	Two levels (40, 55)

a sorghum stem is not tougher than a rice stem, and is easily broken.

The study was conducted using grain of sorghum samples, at three fan speeds (high, middle, and low), three oscillating frequency levels (4.8 Hz, 6.1 Hz, 7.2 Hz), and two chaffer angles (40°, 55°) of the sieve. Grain samples with each weighing 100 g were examined separately. The grain loss rate at the outlet of the cleaning shoe (shown in Fig. 3) was determined using the following equation (1):

$$\text{Grain loss rate (\%)} = (\text{Weight of grains at the cleaning shoe' outlet} / \text{Weight of input grains}) \times 100 \quad (1)$$

Figure 2 shows a view of the rice combine (DSM70). Table 3 presents the experimental conditions for the grain loss measurement of the sorghum at the cleaning sieve of the combine. Table 4 shows the speed of the air fan of the rice combine based on the adjustment position. Table 5 shows the dimensions of the sieve of the rice combine, while Figure 3 presents the shape of the sieve (cleaning shoe) of the rice combine used.

Table 5. Dimensions of the sieve of the rice combine

Parameter	Unit	Value
Chaffer width (W)	mm	695
Full length of chaffer (L)	mm	600
Range of chaffer angle	°	25-55

Figure 3. Shape of the sieve (cleaning shoe) of the rice combine (DSM70).

Table 4. Experimental conditions of the threshing and cleaning parts of the rice combine according to engine speed (Jun et al., 2015)

Speed of engine (RPM)	RPM and peripheral speed of wire-loop threshing drum [(m/s) / RPM]	Frequency of cleaning shoe (sieve) (HZ)	Peripheral and rotating speed of fan (Φ=340 mm) by adjustable lever position [RPM / (m/s)]		
			High	Middle	Low
2,000	10.3 / 352	4.8	1,123 / 20	869 / 15	757 / 13
2,500	13.0 / 443	6.1	1,378 / 25	1,074 / 19	937 / 17
3,000	15.6 / 532	7.2	1,622 / 29	1,280 / 23	1,119 / 20

Experiment 2: Harvesting grain loss test in field using the rice combine with a concave mesh with opening size of 18×18 mm

The tested sorghum plant was planted in a cultivation style with bed width of 1.5 m (Table 6) and 1.2 m of planted width. A rice combine (Model-DSM70) was used for the sorghum harvesting experiments. The rice combine includes parts for cutting, transporting, threshing, separating, cleaning, collecting and discharging, and driving. The cutting width was 1.4 m and the length of the plants for ideal threshing ranged from 0.55 m to 1.3 m. To measure the grain loss while harvesting, the length of the test bed each time was 5 m, and the grain and stems were collected at the outlet of the cleaning shoe of the rice combine. The combine harvesting test was conducted with variety of sorghum Ⅲ (Nampungchal). There were three levels of experimental factors: sieve oscillating frequency (4.8 Hz, 6.1 Hz, and 7.2 Hz) according to engine speed (2,000, 2,500, and 3,000 RPM), and two levels of chaffer angle (40° and 55°). The method was trial and error. The opening size of the concave mesh was 18×18 mm and the air fan speed was set corresponding to the low lever position. The working speed was 0.5 m/s. The chaffer angle of the cleaning shoe was measured horizontally, and the grain loss was calculated using the following equation (2):

Rate of grain loss (%) = (Loss of grain at outlet of cleaning shoe / Average grain of each test bed) × 100 (2)

Table 7 shows the experimental conditions for measuring the harvesting grain loss of sorghum in field while Figure 4 shows the views of grain loss test in field using the combine.

Experiment 4: The harvesting grain loss test according to the opening size of the concave mesh for sorghum using the combine

For measurement of the harvesting grain loss and the decision on the optimal opening size of the concave for harvesting of sorghum using the rice combine, three different sizes of opening of the concaves (Ø11, Ø13, and Ø15) were tested to improve the concave mesh opening of the rice combine for sorghum harvesting. The tested sorghum III was the same as those in Table 6. The grain loss ratio was calculated as shown in Equation 2. The tested length for three rows of sorghum per time was 5 m

Table 6. Properties and cultivation style of the sorghum in the test field

Variety of sorghum	Total height (m)	Length / Diameter of sorghum head (mm)	Moisture of sorghum head (%, d.b.)	Plant bed width (m)	Planted width (m)	Planted row (rows/bed width)
Sorghum III (Nampungchal)	1.54±0.17	230/60	33.4	1.5	1.2	3

Table 7. Experimental conditions for measuring harvesting grain loss of sorghum in the field

Variety of sorghum	Cutting width of the combine (m)	Testing length (m / time)	Size of concave mesh (mm)	Chaffer angle of sieve (°)	Working speed (m/s)
Sorghum III (Nampungchal)	1.4	5	18×18	Two levels (40, 55)	0.5

Harvesting   Loss grain collecting   Chaffer angle adjustable lever

Figure 4. Views of grain loss test in field using the combine.

Table 8. Grain loss rate of the sorghum by air fan adjustment position

Chaffer angle of sieve (°)	Engine speed (RPM)	Frequency of cleaning shoe (Hz)	Grain loss rate of the samples of sorghum by air fan adjustment position (%)		
			High	Middle	Low
40	2,000	4.8	2.0	0.6	0.4
	2,500	6.1	3.5	0.8	0.4
	3,000	7.2	8.3	3.7	1.7
55	2,000	4.8	2.6	0.4	0.4
	2,500	6.1	2.7	1.2	0.7
	3,000	7.2	9.2	2.4	2.0

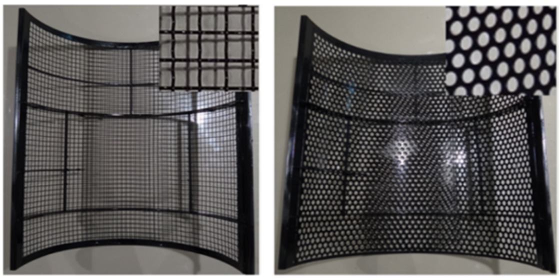

Figure 5. The shapes of the concaves.

at the rotating speed of the air fan in high position, the oscillation frequency of 4.8 Hz, the engine speed of 2,000 RPM, and the running speed of 0.5 m/s. The distribution of the sorghum components was measured and compared. Figure 5 shows the shape of the concaves.

Results and Discussion

Grain loss by the cleaning part of the combine

Table 8 shows the loss rate of grain at different levels of chaffer angle, at different fan speeds, at different cleaning shoe frequencies, and at different engine speeds of the rice combine. In each test using pure grain as shown in Table 4, the least grain loss rate was 0.4% for pure grains at a chaffer angle of 40°, at a cleaning shoe frequency of 4.8 Hz, an engine speed of 2,000 RPM, and at the fan speed of the low position of the fan adjusting lever. At a chaffer angle of 55°, at a cleaning shoe frequency of 4.8 Hz, an engine speed of 2,000 RPM, and at the lowest fan speed, the least grain loss rate also was 0.4%. Accordingly, at a chaffer angle of 40°, a cleaning shoe frequency of 4.8 Hz, an engine speed of 2,000 RPM, and at the lowest fan speed, the factors do not affect the grain loss. However, as the frequency of the cleaning shoe and fan speed were increased, the grain loss rate increased to 2.0% at a chaffer angle of 40° and to 2.6% at a chaffer angle of 55°.

The results showed that the main factors contributing to grain loss when operating the rice combine were the frequency of the cleaning shoe according to the engine RPM, and to the fan speed, for each chaffer angle of the cleaning shoe. However, to use the rice combine to harvest sorghum in fields, a study on the determination of the main factors affecting threshing and cleaning is important because both grain and stems of the sorghum are put together into the threshing device of the rice combine.

The terminal velocity (Vt) of the sorghum was calculated using the following equation (3), which is based on the rate of the moisture content (W) of the sorghum (da Silva et al., 2003).

$$Vt = 0.0668\ W + 4.6063 \tag{3}$$

Vt = Terminal velocity of sorghum (m/s),
W = Moisture content (%) on dry basis

Based on the equation, the terminal velocity of the sorghum ranged from 5.2-6.6 m/s at 9-30% moisture content of the sorghum.

Grain loss of sorghum in the field using a combine concave mesh opening size of 18×18 mm

Table 9 shows the results of the rice combine and loss grain rate at the outlet. The grain loss rate range was 0.1~1.8% with the 18×18 mm concave opening size of the threshing device, 4.8 Hz oscillating sieve frequency of the cleaning shoe device, and 40° chaffer angle. However, at a chaffer angle of 55°, the separation and cleaning work became impossible because of the large amount of stems that got through the concave. The grain loss rate also

Table 9. Grain loss rate based on engine speed and sieve chaffer angle at the outlet of the sieve with the concave opening size of 18×18 mm

Size of concave mesh (mm)	Variety	Grain loss rate at the outlet of the sieve according to sieve frequency at chaffer angle of 40° and low fan position (%)		
		4.8 Hz (Engine 2,000 RPM)	6.1 Hz (Engine 2,500 RPM)	7.2 Hz (Engine 3,000 RPM)
18 x 18	Sorghum I (Sodamchal)	0.1	0.3	1.8

Harvesting of head feeding type rice combine | Stems in concave after operating | Bad sieve separating | Harvested grain in the tank

Figure 6. View of the rice combine harvesting the sorghum.

Table 10. Grain loss and distribution of sorghum components harvested in the tank based on the concave opening size with fan-lever position on High, peripheral fan speed of 20 m/s, and engine speed of 2,000 RPM)

Opening size of round concave holes (mm)	Driving speed of the combine (m/s)	Distribution of the sorghum component harvested in the tank (%)			Grain loss in Sieve (%)
		Total	Grain	Stem	
Ø 11	0.5	100.0	91.1	8.9	1.1
Ø 13	0.5	100.0	91.9	8.1	0.5
Ø 15	0.5	100.0	97.4	2.6	1.1

increased as the frequency of the sieve (cleaning shoe) increased. With an 18×18 mm concave opening size, 4.8 Hz oscillating sieve (cleaning shoe) frequency, and 40° chaffer angle, the results showed the lowest (0.1%) grain loss rate. However, many stems were included in the collection, which interfered with the grain transfer, and continuous harvesting was made difficult because the consecutively fractured stems accumulated. Moreover, as the fan speed increased, the grain loss rate tended to increase rapidly.

Therefore, it was determined that, for continuous sorghum harvesting, the fan speed should be increased, and the opening size of the concave should be reduced.

Figure 6 is a view of the rice combine harvesting the sorghum.

Grain loss and distribution of sorghum components harvested in the tank based on the opening size of open round-hole type concaves in the field

As shown in Table 10, the grain retention rate of the harvested component was 97.4% for the concave opening size of Ø15 mm, and more than 91.9% for a concave opening of Ø13 mm; however, the grain loss rate was 0.5% for the opening size of Ø13 mm, whereas it was 1.1% for Ø15 mm openings. Therefore, the concave opening size of Ø13 mm is the most suitable for sorghum harvesting using a rice combine.

Conclusions

This field study was conducted to investigate the proper concave opening size, chaffer angle of the oscillating sieve, and air fan speed of a head-feeding rice combine used for sorghum harvesting. The harvesting condition at

0.5 m/s working speed and each sieve chaffer angle (40° or 55°) of the rice combine were also investigated. The cleaning grain loss rate of sorghum grain at the cleaning shoe of the rice combine was 0.4% at a 40° sieve chaffer angle, engine speed of 2,000 RPM, 4.8 Hz oscillating sieve (cleaning shoe) frequency, and air fan adjusted to low position. To decrease the stem rate in the harvested components, the opening type and size of concave was changed from the mesh type to the open round-hole type. As a result, it was determined that the optimal operating conditions for the rice combine (lowest grain loss rate at harvest) for sorghum varieties was 0.5% at the opening size of Ø13 mm of the concave, 40° chaffer angle of the sieve, 20 m/s fan speed, and 4.8 Hz sieve frequency at 2,000 RPM of engine speed. Findings showed that it was possible to harvest sorghum using the rice combine. This could reduce sorghum labor costs and harvesting time, and encourage the use of the rice combines.

Conflict of Interest

The authors have no conflicting financial or other interests.

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References

da Silva, F. S., P. C. Corrêa, P. C. Afonso Júnior and A. L. D. Goneli. 2003. Influence of moisture content in the terminal velocity of sorghum and millet. Journal of Revista Brasileira de Milho e Sorgo 2(3): 143-147. http://doi.org/10.18512/1980-6477/rbms.v2n3p143-147

Jun, H. J., I. S. Choi, T. G. Kang, Y. Choi, D. K. Choi and C. K. Lee. 2015. Study on performance improvement of head-feeding rice combine for foxtail millet harvesting. Journal of Biosystems Engineering 40(1): 10-18. https://doi.org/10.5307/JBE.2015.40.1.010

Jun, H. J., I.S. Choi, T. K. Kang, Y. Choi, D. K. Choi and C. S. Hyun. 2014. Characteristics of grain separation of foxtail millet and sorghum for cleaning shoe of head feeding combine. In: *Proceeding of the KSAM 2014 Spring Conference*, pp.151-152, Suwon, Gyeong-gi, Republic of Korea: April 2014(In Korean).

KOSIS (Korea Statistical Information Service). 2009. Area of cereal crops. Availabel at: www.kosis.kr(2018.9.6).

Masane, P. K., V. N. Mate, P. A. Borkar, R. P. Murumkar, M. R. Rajput and P. K. Rathod. 2016. Physical properties of tender sorghum (*Sorghum bicolor* L.) grains. Journal of Ready to Eat Food. 3(4): 51-54.

Nattapol, P., W. Lamul and D. Wasan. 2014. Effect of moisture content on physical and aerodynamic properties of sorghum. Journal of Medical and Bioengineering. 3(3): 167-170. https://doi.org/10.12720/jomb.3.3.167-170

Tarui, F. 1962. Threshing test of wet paddy. Journal of the Japanese Society of Agricultural Machinery 24(1): 37-38 (In Japanese). https://doi.org/10.11357/jsam1937.24.37