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Prototype Development of a Small Combine for Harvesting Miscellaneous Cereal Crops and its Basic Performance

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Abstract

Purpose: The aim of this study is to develop a small combine for harvesting miscellaneous cereal crops. **Methods:** A prototype small combine was designed and constructed. Its specifications and basic performance were investigated. **Results:** The prototype small combine for harvesting miscellaneous cereal crops was designed and constructed to reflect similar specifications as those of the conventional combine. The prototype small combine comprises a diesel engine with the rated power/speed of 22.0 kW/2,600 rpm, three-stage primary and two-stage speed range transmission shifts, and a double acting threshing part. The maximum travel speeds of the prototype combine are approximately 0.72 m/s, 2.50 m/s, 0.30 m/s at the low, high speed range shifts in the forward direction, and while traversing in the reverse direction, respectively. The minimum radius of turning was approximately 1.50 m. In a static lateral overturning test, the prototype combine overturned neither to the right nor to left on a 30° slope. The results of an oilseed rape harvesting test included the maximum operating speed of 0.32 m/s, the grain loss ratio of approximately 9.0%, and the effective field capacity of approximately 10.3 a/h. Additionally, among the outputs in grain outlet, the whole grains, damage grains, and materials other than grain (MOG) ratios accounted for 97.4%, 0.0%, and 2.6%, respectively. **Conclusions:** The prototype small combine for harvesting miscellaneous cereal crops indicates good driving ability and stability. The results of the oilseed rape harvesting test reveal that the harvesting performance must be enhanced such that the separating and cleaning parts are more suitable for each type of crop, thus reducing grain loss and foreign substances among the outputs in grain outlet. An improved small prototype combine could be used effectively to mechanize the harvesting of miscellaneous cereal crops in small family farms or semi-mountainous areas.

Keywords: Harvesting performance, Miscellaneous cereal crops, Prototype small combine

Introduction

The majority of high income miscellaneous cereal crops including adlay and buckwheat is cultivated primarily by small family farms in semi-mountainous areas. Hence, these crops are difficult to harvest in a mechanized manner. Some farms use the latest developed threshers for miscellaneous cereal crops. In such a case, however, the harvesting process depends almost entirely on manpower. Additionally, a large conventional combine is difficult to use in a semi-mountainous area. Accordingly, the development of an efficient low-cost small combine for harvesting miscellaneous cereal crops in small family farms is highly demanded.

Most of the conventional combines that can be used widely to harvest pulses and other miscellaneous cereal crops, are imported products of large size. Most of the latest combines developed domestically for pulses are middle- or large-sized machines of power 45 kW or beyond. South Korea is in the early stages of spreading combines for pulses as the first domestic combine for

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beans was developed recently (FACT, 2018), and the first domestic pick-up-type combine for pulses that were cut and dried, have also appeared recently (Lee et al., 2017). Apart from pulses, a thresher for small-grained crops such as millet, teff, and sorghum (Chung et al., 2011), and a thresher for sesame (Lee and Noh, 2015) were also developed. The performance of a head-feed combine for harvesting millet was examined (Jun et al., 2015). Other studies on the performance of the conventional combines for harvesting oilseed rape (Lee et al., 2008a, 2008b, 2009a, and 2009b) have been reported. Nevertheless, in general, only few studies have attempted to develop a combine or harvester appropriate for miscellaneous cereal crops, and improved the harvesting performance.

In this study, we designed and constructed a small combine for harvesting miscellaneous cereal crops. It is useful for small family farms or semi-mountainous areas, and is evaluated based on basic performance including major specifications, driving ability, stability, and oilseed rape harvest.

Materials and Methods

Design concept of the prototype small combine

The prototype small combine for harvesting miscellaneous cereal crops in this study was tried to develop a small and compact cutting crop full-feeding conventional combine with the rated power/speed of 22.0 kW/2,600 rpm, which had the cutting width of 1.2 m or could harvest 2 rows. By simple changing operation condition and replacing grain sieve according to harvesting crop, the prototype was designed to harvest miscellaneous cereal crops such as rape, bean, buckwheat, and adlay. The prototype was tried to be small and compact size for allowing old man and woman operation, and transporting by a 2-ton truck. Its harvesting speed for miscellaneous cereal crops was considered to be approximately below 0.7 m/s, and the mass was designed to be below 1,700 kg compared with that in the 2,910-5,010 kg range of the mid-sized conventional combine with the rated power in the approximately 31-85 kW range (FACT, 2018). Thus it was designed to be appropriate for small scale family farms in semi-mountainous areas. For facilitating small family farms and the farm machinery rental service centers uses in Korea, the purchasing price of the prototype was tried to become below half compared with that of approximately 100 million won of the mid-sized conventional combine with the rated power of about 50 kW (FACT, 2018).

Prototype's primary specifications and basic performance testing

The primary specifications including the forms and dimensions of the primary parts of the prototype combine, which were designed and constructed in this study, were investigated. Additionally, the travel speeds, brake performance, turning radius, the driving performance of the primary parts at each stage of the power transmission under no load on a plane concrete road, the maneuverability and stability of the machine were tested. The stability of the machine was tested by using the lateral overturning angle tester in The Foundation of Agriculture Techniques Commercialization and Transfer (FACT, Jeonlabuk-do, Korea). All of these tests were conducted in accordance with the comprehensive testing methods and standards for the cutting crop full-feeding conventional combines (FACT, 2014 and 2016).

The harvesting performance test of oilseed rape was performed for the combine prototype from 19 to 20 June, 2017 in the Nakdong River oilseed rape complex located in Namji-eup, Changneoyng-gun, Gyeongsangnam-do. Oilseed rapes cultivated by broadcast sowing were used. The moisture content of oilseed rape was approximately 15.2% (GMK-303F, G-Won Hightech Co., Korea). The harvesting performance test was performed by two times on a field, of which the longer side was 80 m and the shorter side was 25 m. The prototype combine was operated at the low speed of the speed range transmission shift and at the first stage of the primary transmission shift. Further, the rotating harvesting method was applied. The operating speed, field capacity, grain loss ratio, and ratios of whole grains, damaged grains, and materials other than grain (MOG) among the outputs in grain outlet were verified in accordance with the terminologies and comprehensive testing standards for the cutting crop full-feeding conventional combines (FACT, 2016). The standing angle of the crop, which enables the cutting work, was also examined.

Results and Discussion

Primary specifications of the prototype

Figure 1 shows the prototype combine that was constructed for harvesting miscellaneous cereal crops in this study. The dimensions of the machine were 4,210 mm × 1,860 mm × 2,300 mm in length, width, and height, respectively. The machine weighed approximately 16.5 kN, and had minimum ground clearance of approximately 200 mm. Table 1 presents the specifications of the primary parts of the prototype combine.

Figure 1. Photograph of the prototype small combine for harvesting miscellaneous cereal crops.

Layout of prototype's primary parts

Engine, power transmission, crawler, and hydraulic circuit

The engine of the prototype combine was a water-cooled four-stroke and three-cylinder diesel engine with

Table 1. Specifications of the prototype small combine

Item	Specifications
Engine	Manufacturer/Model: Kukje/ A1100T2-KTR-4 Type: water cooled, 4-stroke, 3 cylinders, diesel Displacement: 1,175 cc, rated power/speed: 15.5/3600 kW/rpm
Transmission	Primary transmission shift: selective gear type high, middle, low 3 stages Speed range transmission shift: selective gear type high, low 2 stages
Crawler	Width x Length: 280 x 920 mm, lug height: 30 mm, no. of link: 38, crawler tread: 775 mm, ground contact pressure: 32.6 kPa
Steering	Steering clutch type
Brake	Wet disk type, mechanical pedal
Hydraulics	Hydraulic pump: gear type, displacement 15 cc/rev., max. pressure 13.7 MPa Header cylinder: inner diameter 70 mm, stroke 240 mm Reel cylinder: inner diameter 50 mm, stroke 90 mm
Reel	Diameter 620 mm, no. of tine 64, pitch of tine 85 mm,width of reel 1.75 mm, reel speed 52 rpm
Cutter	Reciprocating type, width of cutting 1,200 mm, range of cutter height 55-740 mm, no. of cutting blade 15, pitch of cutting blade 76 mm, stroke of cutting blade 76 mm, cutting speed 1.32 m/s
Platform auger	Diameter of auger cylinder 200 mm, height of auger screw 80 mm, auger clearance 15 mm, auger speed 213 rpm
Feeder conveyer	Chain conveyer with angle bar type, width x height x length 430 x 1,418 x 1,250 mm, pitch of angle bar 150 mm, feeding speed 2.0 m/s
Threshing part	#1 threshing cylinder: dia. 425 mm, length 485 mm, 7 mm steel wire teeth, no. of teeth 30, height of teeth 55 mm, cylinder speed 405 rpm, speed of teeth end 11.3 m/s #2 threshing cylinder: dia. 325 mm, length 485 mm, 7 mm steel wire teeth, no. of teeth 20, height of teeth 55 mm, cylinder speed 598 rpm, speed of teeth end 13.6 m/s Concave: steel plate with circular holes, hole size 12Φ Cutting knives: triangle, height x thickness 25 x 3.2 mm, no. of knives 5/row x 10 rows
Separating and cleaning part	Straw walker: width x length 90 x 1,500 mm, opening size 20 x 30 mm Grain pan: tilting angle 5°, no. of opening holes 325, hole dia. 10Φ Grain sieve: : tilting angle 5°, no. of opening holes 725, hole dia. 10Φ Fan: centrifugal type, no. of blade 4, speed 1,540 rpm Oscillating arm: speed 350 rpm, oscillating stroke 30 mm
Tailings rethreshing part	Horizontal conveying auger: outer dia. of screw 120 mm, dia of shaft 20 mm, screw pitch 108 mm, speed 178 rpm Tailings distribution auger: outer dia. of screw 120 mm, dia of shaft 20 mm, screw pitch 108 mm, speed 337 rpm Vertical conveying bucket elevator: vol. of a bucket 230 cm^3, no. of buckets 19, speed 2.4 m/s
Grain conveyer and grain tank	Horizontal conveying: tilting steel plate Vertical conveying bucket elevator: vol. of a bucket 230 cm^3, no. of buckets 30, speed 2.7 m/s Grain tank: capacity 200 L, size of grain outlet 150 x 120 mm

the displacement of 1,175 cc, the rated power/speed of 22.0 kW/2,600 rpm, and the maximum torque of 80.7 N-m/2,000 rpm.

Figure 2 shows the power flow diagram from the engine to the primary parts of the prototype combine. As illustrated in Figure 2, the engine power is transmitted to the primary parts through a V-belt and roller chain gears. The primary parts of the prototype combine are driven in the following orders: engine – hydraulic pump of hydraulic circuit, engine - power transmission with selective mesh gears (three-stage primary and two-stage speed range transmission shifts) – crawler, engine – fan and oscillator for separating and cleaning grains, engine – threshing cylinder #1 – feeder conveyer for cut grains – platform auger and reel of header part, reciprocating cutter, engine – threshing cylinder #1 – threshing cylinder #2 – upper and lower tailings augers – tailings bucket elevator, engine - threshing cylinder #1 – threshing cylinder #2 – grain bucket elevator.

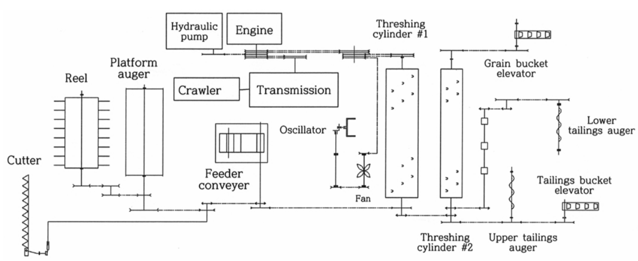

Figure 2. Power flow diagram for the prototype small combine.

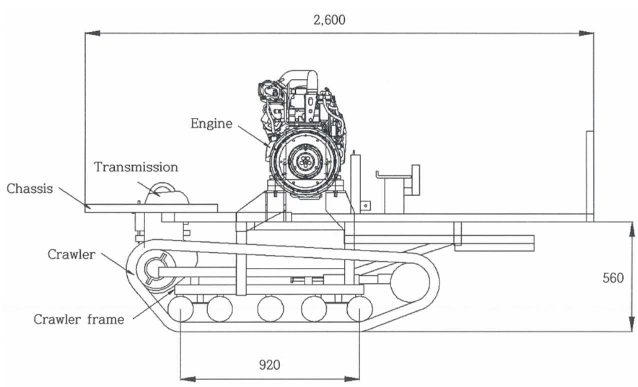

Figure 3. Arrangement of the engine, transmission, crawler, and chassis.

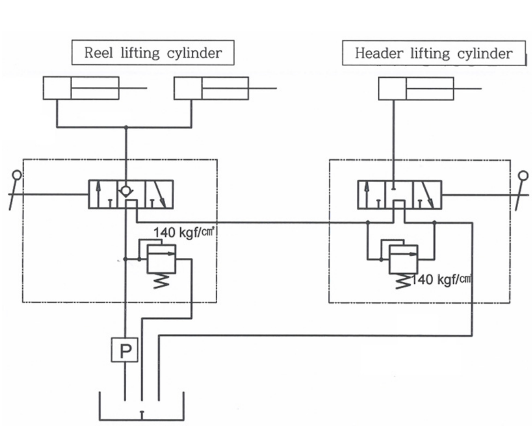

Figure 4. Hydraulic circuit for the prototype small combine.

As shown in Figure 3, the crawler-type driving unit of the prototype combine consisted of a crawler, driving sprocket, wheels for supporting the crawler, wheels for adjusting the crawler tension, and crawler frame to achieve an improvement in driving ability for uneven fields or slopes. The hydraulic circuit for lifting the header and adjusting the height of the reel from the cutter is shown in Figure 4.

Header

As shown in Figure 5, the header part of the prototype combine was designed and constructed with the same structure as the conventional combine header. The distance between the tips of the left and right dividers was 1,200 mm, and the distance from the cutter to the tip was designed to be 280 mm. The reel was rectangular, and a pick-up tine was attached to the reel bar. The relative location of the reel for the cutter was adjusted vertically by the hydraulic cylinder and horizontally by manually changing the attachment position on the holes of the reel axis frame. The reel was designed to rotate at approximately 52 rpm under the rated rotation speed

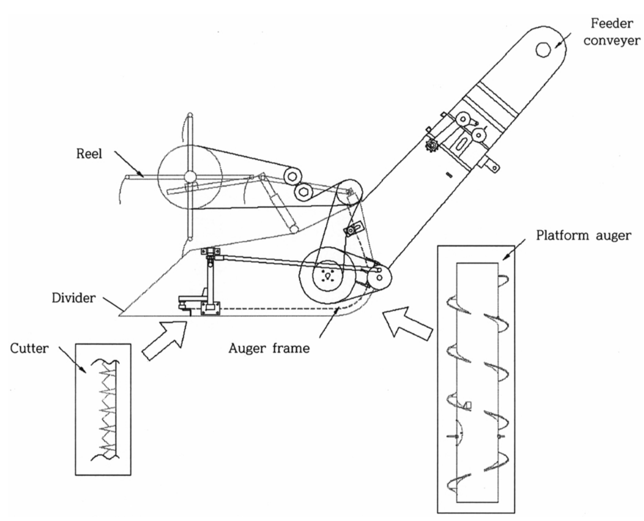

Figure 5. Arrangement of the divider, reel, cutter, platform auger, and feeder conveyer.

of the engine. From the cutter, the reel exhibited the maximum height of 740 mm, and its distance was adjusted to be -50, 50, 100, and 150 mm in the front and rear directions. The cutter comprised 15 reciprocating-type 76-mm blades. Cutting blades was 1,200 mm wide, and its cutting speed at the rated rotation speed of the engine was approximately 1.32 m/s. The platform auger, which delivers the collected and transmitted cut crops to the feeder conveyer, included a cylinder of diameter 200 mm, a helix of height 80 mm, and rods. The platform auger was designed to rotate at approximately 213 rpm while the engine rotates at its rated speed. Figure 6 presents the structure of the feeder conveyer transmitting cut crops from the platform auger to the threshing device. As illustrated in Figure 6, angle bars were attached to the chain conveyer. The feeding speed was approximately 2.0 m/s at the rated speed of the engine.

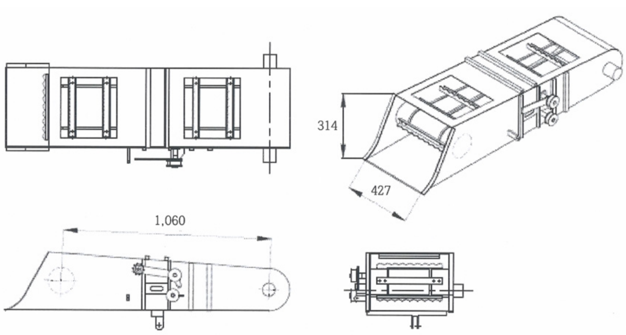

Figure 6. Structure of the feeder conveyer.

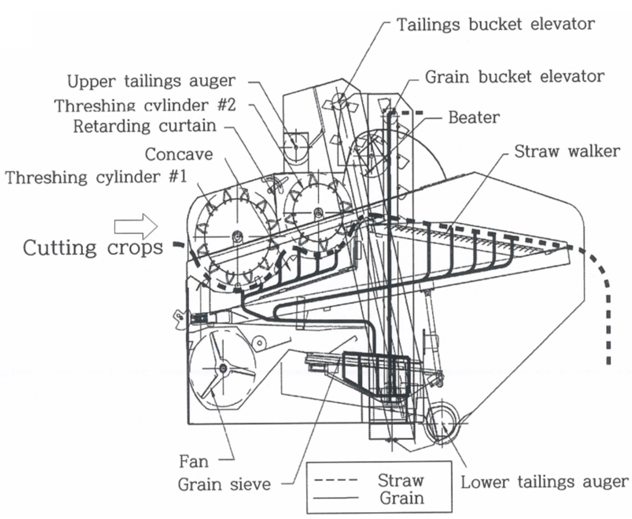

Figure 7. Sectional view of the threshing, separating and cleaning, tailings rethreshing, and clean-grain conveying parts.

Threshing, separating and cleaning, tailings rethreshing, and clean-grain conveying parts

Figure 7 illustrates the structures of threshing, separating/cleaning, tailings rethreshing, and clean-grain conveying parts, and also shows the flow of straws and separated clean grains of the cut crops.

Double threshing cylinders (cut corps flow perpendicular to the axis of the threshing cylinder) were applied to the thresher of the prototype combine. Both the cylinder #1 and #2 were 485 mm wide. Their diameters were 425 mm and 325 mm, respectively. They were designed to rotate at approximately 405 rpm and 598 rpm, respectively, under the rated rotation speed of the engine. Steel wire teeth of 7 mm were used for the thresher. The height of a tooth was 55 mm. The cylinder #1 and #2 contained 30 and 20 teeth, respectively. To improve the threshing performance, the cylinder #1 and #2 exhibited different teeth end speeds of approximately 11.3 and 13.6 m/s, respectively. The concave used a steel plate with 12 mm circular holes. A total of 50 triangular cutting knives were arranged in 10 rows to cut crop stalks.

The separating and cleaning system used the combination of oscillation and air blow, and comprised a straw walker, grain pan, chaffer sieve, grain sieve, blowing fan, and oscillator. Figure 8 illustrates the structures of those components except blowing fan. The oscillating arm rotated at 350 rpm under the rated rotation speed of the engine, and the oscillating stroke was 30 mm. The blowing fan shown in Figure 7 was a centrifugal type with four blades, and was driven at approximately 1,540 rpm under the rated rotation speed of the engine.

The tailings rethreshing part shown in Figure 7 included a horizontal conveying auger, a vertical conveying bucket elevator, and a tailings distribution auger. Both

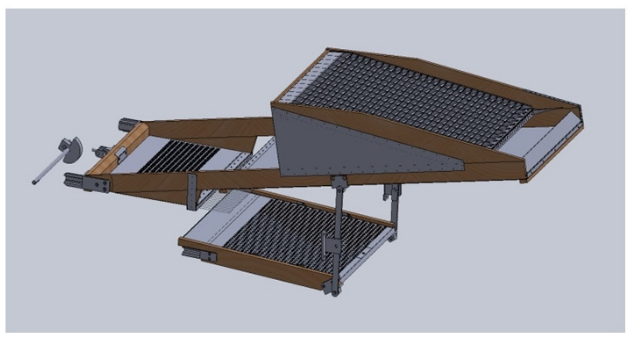

Figure 8. Structural view of the straw walker, grain pan, chaffer sieve, grain sieve, and oscillator.

the horizontal conveying auger and the distribution auger exhibit the following parameters: shaft diameter of 20 mm, screw diameter of 120 mm, and screw pitch of 108 mm. These augers were designed to rotate at approximately 178 rpm and 337 rpm, respectively, under the rated rotation speed of engine. The volume of the bucket elevator was 230 cm^3. The number of buckets was 19, and the bucket pitch was 170 mm. The bucket speed was approximately 2.4 m/s under the rated rotation speed of the engine.

To prevent the grains from being damaged, the grain cleaning-conveying part in Figure 7 used a tilting steel plate instead of the conventional auger for horizontal conveyance, and a bucket elevator for vertical conveyance. The volume of the bucket elevator was approximately 230 cm^3. The number and pitch of the bucket were 20 and 170 mm, respectively. The bucket speed was approximately 2.7 m/s under the rated rotation speed of engine.

Grains in the grain tank could be put into a bag at the outlet, and the capacity of the tank was approximately 200 L.

Operational control and safety parts

Figure 9 shows the arrangement of the operational control parts including the primary and speed range transmission shift levers beside the driver's seat, brake pedal, height control levers for the reel and header, steering levers for the left and right turning, lighting lamp combination switch, cutting and threshing clutch switch, accelerator lever, starter switch, safety handle, and dashboard.

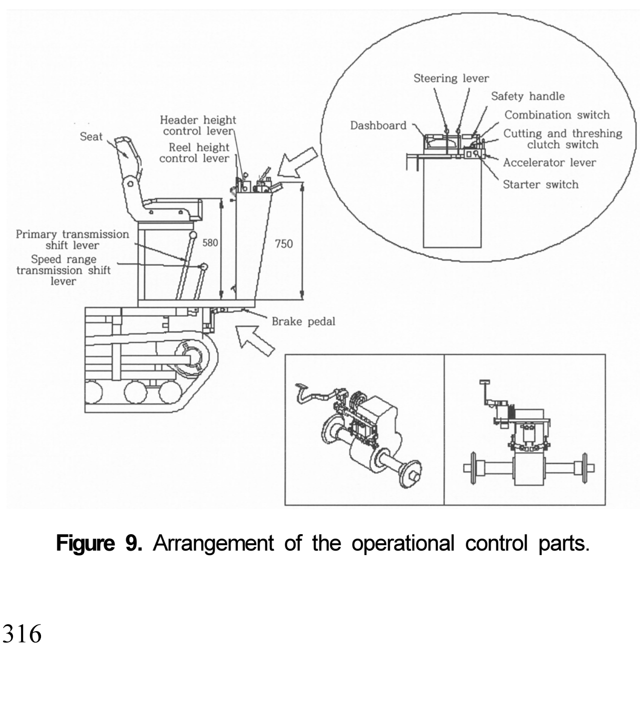

Figure 9. Arrangement of the operational control parts.

The engine could start only when the brake is turned on, and the cutting and threshing clutch lever was turned off. Other safety devices were also included such as a header drop prevention device, cutting and threshing clutch switch for stopping the cutter and the threshing part, an alarm device indicating the full load of the grain tank, reverse traversing, and a slope of 10° or beyond. For safety reasons, protective steel covers were installed on the driving part of the chain and V-belt conveyers power transmission device of the reel, threshing cylinder, feeder conveyer, and platform auger.

Handles were installed near the driver's seat to help the driver board or alight the machine. The steps for boarding or alighting the machine, and the pedals were made of embossed steel plates to avoid a slip. A rubber buffer was used for the driver's seat to reduce vibrations. The position of the seat could be adjusted to 60 mm in the front and rear directions. The dashboard in front of the seat included a tachometer, traversing hour meter, fuel gauge, and coolant temperature gauge. A coolant warning light, engine oil warning light, and battery charge indicator were also installed.

To ensure worker safety, the body of the prototype combine contained various safety signs and labels for the warnings of overheated engine, high temperature, and high fuel injection. Thus, contacts with rotating components and boarding the threshing part are prohibited. The warnings serve as a reminder to stop the engine during maintenance, observe the check and repair of the threshing part and the danger within the operating radius, use a fixed device of the cutter, and be cognizant of the safety of boarding and alighting the combine.

Basic performance of prototype

Travel speed and minimum turning radius

Table 2 provides the travel speeds of the prototype small combine at each stage of power transmission while the engine rotated at its rated speed under no load conditions. The maximum travel speeds were approximately 0.72 m/s, 2.50 m/s, and 0.30 m/s at the low, high speed range transmission shifts in the forward direction, and while traversing in the reverse direction, respectively. It was considered that the travel speed range of 0.35-0.72 m/s at the low speed range transmission shift is proper for old man and woman to harvest miscellaneous crops such as bean, buckwheat, and adlay in semi-mountainous

Table 2. Travel speed of the prototype small combine by the transmission stage

Stage of speed range transmission shift	Stage of primary transmission shift	Travel speed (m/s)
Low	Low	0.35
	Middle	0.49
	High	0.72
	Rearward	0.30
High	Low	1.12
	Middle	1.90
	High	2.50

areas. The driving ability for forward traversing was also good. The minimum turning radius appeared to be approximately 1.50 m.

Maneuverability and stability

The primary and range transmission shift levers, steering lever, lifting lever of the cutter, threshing and cutting clutch lever, and lighting lamp switch exhibited no peculiarities in the maneuverability and stability tests. Further, when the machine was stopped, the reel and head parts were elevated 1,000 times consecutively and no abnormality was observed.

A static lateral overturning test was also performed. The prototype combine did not overturn neither to right nor to left on a 30° slope, and the alarm was operated at the overturning angle of 10° or beyond to both the right and left. The stopping distance was 1.0 m or less when the brake system was operated for the traversing machine. While the parking brake was pressed, the machine did not move to either the front or rear on a 20° slope (Yoo et al., 2016). developed the pick-up type 52 kW conventional combine for pulse crops, which had the left and right lateral overturning angles of 29.6˚ and 31.0˚, respectively. In harvesting performance tests for bean on side-hill field has slope angle ranges of 2-7° in before and behind direction, and 7-14° in right and left direction, overall harvesting performance of the combine was good on side-hill field at operating speed of 1.9 m/s except that separating and cleaning loss ratio in dust outlet increased. Because most upland crop fields locate on below 10˚ slope in Korea, and the prototype combine in this study showed the left and right lateral overturning angles of above 30°, it is expected that the prototype combine could be used to benefit miscellaneous cereal crops harvesting on small slope farm field.

Figure 10. Photograph of oilseed rape harvesting.

Harvesting performance for oilseed rape

Figure 10 shows a photograph of the prototype combine harvesting oilseed rapes. While the oilseed rape harvesting test was conducted, the prototype combine could operate at the maximum operating speed of 0.32 m/s in the first stage of both sub and primary transmissions. The effective field capacity was approximately 10.3 a/h. The prototype combine demonstrated the grain loss ratio of approximately 9.0%. The whole grains, damaged grains, MOG, and unthreshed grain ratios among the output in grain outlet constituted 97.4%, 0.0%, 2.6%, and 0.0%, respectively.

The maximum operating speed and the effective field capacity of the prototype combine were in the 1/3–1/4 range compared with those of the 51 kW conventional combine (CT-2100A, Asia technology, Korea), which had cutting width of 2.1 m (Lee et al., 2008b and 2009a). The Foundation of Agriculture Techniques Commercialization and Transfer (FACT) provides the performance criteria for harvesting oilseed rape that ratios of grain loss, materials other than grain (MOG), and unthreshed grain should be below 10, 3, and 1%, respectively (FACT, 2014). Thus, the prototype combine in this study passed the combine test criteria by FACT. The grain loss ratio have been reported to be 20–50% by MacLeod (1981), approximately 11% by Price et al., (1996), approximately 8.2% by Shibuya (2006), and approximately 5.7–5.9% by Lee et al. (2008a). Thus, the result of this study appeared to be worse than those published since the 2000s. While Lee et al., (2009b) proposed 27–35% as the appropriate moisture content of harvested oilseed rape, that of the oilseed rape used for this study was as low as 15.2%. The ratio of MOG among the output in grain outlet was much higher than approximately 0.1% reported by Lee et al. (2008a). Accordingly, it is necessary to improve the grain sieve and the cleaning shoe for reducing the ratios of grain loss, and MOG.

Conclusions

In this study, we designed and constructed a prototype small combine for harvesting miscellaneous cereal crops. We also examined the major specifications and evaluated the basic performances such as driving ability, stability, and oilseed rape harvesting performance. The oilseed rape harvesting test for the prototype combine indicated that the harvesting performance including the grain loss and MOG ratio among the output in grain outlet must be enhanced by improving the separating and cleaning parts. If the performance of the prototype combine was improved as required above, the combine could be used effectively to mechanize the harvesting of miscellaneous cereal crops in small family farms or semi-mountainous areas.

Conflict of Interest

The authors have no conflicting financial or other interests.

Acknowledgement

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