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Research Article

Comparison of field performances between two typical mini combine harvesters in grain corn production

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Abstract

A mini combine harvester was efficiently designed and developed to harvest grain corn on a small scale farm in order to reduce manpower and operating time as delayed harvesting leads to grain loss. Two typical mini combine harvesters namely Kubota DC105X (*KDC*) and World Star 7.0Plus (*WS*) have been introduced to farmers as high output, low fuel consumption and ease of maintenance in grain corn production. This research was undertaken to evaluate and compare the field performance of *KDC* and *WS* mini combine harvester which included the field efficiency (FE), effective field capacity (EFC), fuel consumption (FC), field machine index (FMI) and total field time under similar field condition and soil properties. A time-motion study was conducted during harvesting in two consecutive growing seasons. The mean values of EFC, FE, FC, FMI and total field time for *KDC* were found to be 0.28 ha/hr, 50.00%, 16.85 l/ha, 0.84 and 3.55 hr/ha, respectively. The mean values of EFC, FE, FC, FMI and total field time for *WS* were found to be 0.25 ha/hr, 54.35%, 12.57 l/ha, 0.81 and 3.99 hr/ha, respectively. The statistical analysis (ANOVA) shows that there were no significant differences in field performance between both mini combine harvesters at 5% significance level ($\alpha = 0.05$). Both mini combine harvesters had performed with consistent and reliable results in conducting the harvesting. This study concludes that the *WS* is more efficient than *KDC* in terms of FE and FC.

1. Introduction

Corn or maize (*Zea mays* L.) which is originated from Mexico is the most demanded, valuable and strategic crops worldwide (Subedi et al., 2009 & Shamsabadi et al., 2017). It is the third largest agricultural crops in the world after rice and wheat (Nor et al., 2019). In Asian countries, about 62% of their corn production was consumed in the form of animal feed (Al-Mitewty et al., 2019). Base on uses, the corn is classified as grain corn, pop corn, sweet corn, baby corn, and silage corn. The grain corns refer to flour, dent and flint corns that are mainly used for human consumption, animal feed and industrial uses such as corn flour, starch, ethanol and others (Subedi et al., 2009).

Grain corn plays a major role in the food, feeds and seed industries (Nor et al., 2019). Thailand, Indonesia, Philippines, and Vietnam produced 5.3, 11.9, 8.2 and 3.95 million tons of grain corn, respectively (USDA, 2018). In Malaysia, 84 thousand tons of grain corn was produced in 2018 (FAO, 2019). Malaysia imports most of its grain corn from South America with 80% coming from Brazil and Argentina (USDA, 2019). Nor et al. (2019) reported that the import of grain corn in Malaysia has increased from 1.196 million tons in 1985 to 2.309 million tons in 1995 and continued to surge to four million tons in 2018. Steadily growth in demand for poultry feed in 2019 resulted in 3.85 million metric ton increase in grain corn consumption forecast in Malaysia (USDA, 2019). Therefore, the ability to produce 30% of grain corn production was the main concern of the Malaysia government to reduce the cost of import (Nor et al., 2019).

Mechanization in a small scale farm such as grain corn production has to play a major role in the future to increase production and productivity in rural areas (Yadav et al., 2013). In grain corn production, harvesting and threshing are the most important operations in the entire range of field operations, which are laborious involving human drudgery (Hossain et al., 2015). To reduce the harvesting loss and cost, timely harvesting is very important, as delayed harvesting leads to a considerable loss of grain. Hence, the usages of mini combine harvesters among farmers have become an alternative solution to reduce manpower and operating time in the grain corn harvesting (Akhir et al., 2018). Recently, there are more than 1500 units of combine harvester with different models and specifications in Malaysia (Taufik et al., 2018). Wagiman et al. (2019) stated that several contractors have initiated the use of a mini combine harvester which is smaller and lighter than large conventional combine harvester. A well designed, combine harvester such as mini combine harvester can play an important role in harvesting in time, efficiently and in less cost (Hossain et al., 2015). Thus, the accurate measurements of the field performance parameters for monitoring machinery performance are required for farm machinery management decisions especially in grain corn production (Al-Aani et al., 2016).

Therefore, the propose of this research is to measure and compare the field performance which included effective field capacity, field efficiency, fuel consumption, field machine index and field time distribution between two typical models of mini combine harvesters under Malaysian farm condition and situation in grain corn production.

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2. Material and methods

2.1. Study area

The chosen study area is located at Labis, Johor, Malaysia (2°21’39” N – 102° 56’ 13” E) under the management of National Farmers Organization (NAFAS). All harvested plots were subjected to the same weather (sunny day) condition with sandy loam of soil texture at the same location in two consecutive growing seasons. Total harvested area for this study was 4.5 hectares with 0.25 ha for each plot. Measuring tape was used for measurement the area in each plot and the data were randomly collected from 18 different plots according to CRD (Completely Randomized Design) system (Smith et al., 1994).

2.2. Combine harvester

Two mini combine harvesters which namely Kubota DC105X (*KDC*) and World Star 7.0Plus (*WS*) which both were imported from Japan and China, respectively, were selected for this research as illustrated in Figure 1 and 2. These models were predominantly used by National Farmers Organization (NAFAS) and Malaysian Department of Agriculture (DOA) for grain corn harvesting. The technical details and specifications of both mini combine harvesters are shown in Table 1. The combine harvester specification, fuel consumption and time-motion record were collected for the analysis.

Figure 1. Mini combine harvester in operation (model Kubota DC 105X)

Figure 2. Mini combine harvester in operation (model World Star 7.0Plus)

Table 1. Specification of two typical mini combine harvesters in the grain corn harvesting

Specification	*KDC*	*WS*
Brand	Kubota	World Star
Model	DC 105X-V3800DI-TIE2-CT	WS 7.0Plus
Overall length, mm	5460	5150
Overall width, mm	3045	2620
Overall height, mm	3040	3030
Minimum ground clearance, mm	325 to 425	360
Weight, kg	4630	3400
Engine Type	Water-cooled four-cycle four-cylinder vertical diesel engine	Vertical, Water cooling, 4x4 strokes direct inject, turbocharger
Engine output, kW(hp)	77.20(104)	76.06 (102)
Power to weight, kW/kg	0.02	0.02
Rotation speed, rpm	2600	2600
Fuel	Diesel	Diesel
Fuel tank capacity, litre	105	130
Working width, mm	2667	2200
Grain tank capacity, litre	2350	1600
Rubber track size, mm	575 x 1900	550 x 2100
Operator	1 person	1 person

2.3. Measurement of operation times

The tasks during field operation which consist of time required for harvesting (time spent in performing the actual harvesting by cutting the plant), reversing and cornering (time spent in turning the combine harvester without cutting the plant), unloading (time spent in unloading the grain tank of the combine harvester and going to or from corn conveying trucks) and machine adjusting or setting (time spent in adjusting or setting the machine) were recorded using stop watch (Doungpueng et al., 2018). Time-motion study was conducted to determine forward speed (FS), effective field capacity (EFC), field efficiency (FE) and field machine index (FMI). FS of each mini combine harvester was determined by recorded the time taken to travel at measured distance. The time was counted was counted using a stop watch and the travelling distance included area of plot size were measured using measuring tape (Smith et al., 1994). Such procedure were carried out for each mini combine harvester to have the average theoretical speed by marking off the 27 m (88 ft) in the field, placing a stake at each end, and counting the second it takes to drive between the stakes (Hanna, 2016).

2.4. Determination of field efficiency

EFC is the actual average working rate per area and TFC is calculated by multiplying machine FS by the effective working width of the machine (Helmy et al., 2010). The ratio of EFC to TFC is called FE and it accounts for failure to utilize the full operating width of the machine and many other time delays (Hanna, 2016). The equation of FE, EFC and TFC were shown in Eqs. (1), (2), and (3) as defined by ASAE standards S495.1 (ASAE et al., 2005).

$$FE = \frac{\mathrm{EFC}}{\mathrm{TFC}} \times 100\% \quad (1)$$

Where FE is field efficiency (%), EFC is effective field capacity (ha/hr) and TFC is theoretical field capacity (ha/hr).

$$TFC = \frac{\mathrm{W} * \mathrm{S}}{10} \quad (2)$$

Where TFC is theoretical field capacity (ha/hr), W is width of machine (m) and S is speed of machine (km/hr).

$$EFC = \frac{\mathrm{A}}{\mathrm{T}} \quad (3)$$

Where EFC is effective field capacity (ha/hr), A is harvested area (ha) and T is total working time (hr) in the field.

2.5. Determination of field machine index

FMI is an indication of how well a specific field is adapted for the use of machinery on it. It is the ratio of the productive machine time to the sum of productive machine time plus the row-end turning time (Shamsiri et al., 2013).

$$FMI = \frac{\mathrm{EOT}}{(\mathrm{EOT} + \mathrm{Turning\ time})} \quad (4)$$

Where FMI is field machine index, EOT = effective operating time which means harvesting (hr); Turning time = row-end turning time (hr).

2.6. Determination of fuel consumption

The fuel consumption measurement was carried out by refilling the diesel fuel tank back to its full capacity using a measuring cylinder. The difference in volume before and after refilling was measured as diesel fuel consumption in litres (ASABE., 2011).

3. Results and discussion

3.1. Field performance evaluation

Field performance was measured to evaluate the efficiency of the mini combine harvester in actual field conditions which is significantly important in farm machinery management for further improvement and rectification to increase agricultural productivity and minimize the cost of operation. Table 2 shows the comparison results of of field performance between *KDC* and *WS* in grain corn harvesting.

3.2. Effective field capacity and field efficiency

Table 2 illustrates that the mean EFC of *KDC* and *WS* in grain corn harvesting were 0.28 and 0.25 ha/hr, respectively. *WS* had 10.71% less of mean EFC than *KDC* because it had 17.60% less working width (Table 1 and 2). Less working width resulted in less EFC and the working width indirectly proportional to the mean EFC. Table 2 shows that the mean FE of *KDC* and *WS* harvester in grain corn harvesting was 50 and 54.35%, respectively.

A recent study showed that *WS* had also been used in wetland paddy harvesting with mean FE of 72% (Elsoragaby et al., 2019). High EFC can have low FE for instance, *KDC* which had 12% higher EFC, had 8% lower in FE than *WS* due to underutilization of working width (Table 3). Failure to utilize the full operating width of the machine would decrease the FE (Hanna, 2016). This finding has also been explored in a previous study which indicated that the maximum value of EFC (0.52 ha/hr) had 21.93% lower of FE than minimum EFC (0.32 ha/hr) with the same length of working width (1.98 m) of same mini combine harvester (DC 70GPlus) (Akhir et al., 2018). Therefore the size and working width utilization have great influence in determining the value of EFC and FE. It can be understood from the Eqs. (1) which stated that the high FE depends on how close the value of EFC to TFC at optimum working speed with fully utilization of operating working width.

As shown in Table 3, *KDC* and *WS* harvester had mean FS of 3.82 and 3.13 km/hr, respectively. A 22.04% higher forward speed (FS) by *KDC* resulted in 12% higher of EFC than *WS*. Similar finding found by Helmy et al. (2010) in rice field which revealed that by increasing the FS from 2 to 5 km/hr (150%), the EFC increased by 127.12%. In general, the EFC increases as the FS increases in harvesting as stated by Bawatharani et al. (2015).

3.3. Fuel consumption analysis

As shown in Table 2, the mean FC in grain corn harvesting for *KDC* and *WS* were 16.85 and 12.57 l/ha, respectively. *KDC* with mean EFC of 0.28 ha/hr contributed to 34.05% higher mean FC than *WS*. In paddy harvesting with mean EFC of 0.53 ha/hr, the *WS* consumed 18.46 l/ha (Elsoragaby et al., 2019). The results stated that the grain corn harvesting which consumed 12.57 l/ha of diesel had 31.91% lower fuel consumption than paddy harvesting per hectare with the same model *WS* (Elsoragaby et al., 2019). Under these circumstances, in terms of fuel consumption per unit time (l/hr), the *WS* consumed 12.04% lower fuel consumption (3.14 l/hr) than *KDC* (4.72 l/hr) (Table 2). In other words, even though the EFC of *KDC* is 12% higher than *WS*, the *WS* is more fuel-efficient in term of volume (diesel fuel consumed) per hour, (l/hr) and volume (diesel fuel consumed) per hectare of harvesting area (l/ha). *WS* consumed 25.4% lower fuel because of 18.06% lower FS than *KDC* (Table 2). Previous research conducted in winter wheat harvesting using Claas Lexion 540C combine harvester reported that the increase of speed by 1 km/hr caused the rise of fuel consumption by 1.3 l/hr (Spokas et al., 2015). From the analysis, it was found that the FC and EFC increase as the FS increases.

3.4. Field machine index

FMI of the *KDC* and *WS* were 0.84 and 0.81, respectively (Table 2). Wagiman et al. (2018) reported that the mini combine harvester (DC 95M) in paddy field had FMI of 0.87. Shamsiri et al. (2013) clarified that the FMI is useful in predicting machine capacity and determining the machinery needs and hours of use. The author stressed that the value of FMI is higher as the turning time is lower.

3.5. Field time distribution evaluation

FE was influenced by field time distribution which includes harvesting, cornering, reversing, unloading, machine adjustment and setting. Field time distribution is imperative in order to determine the required working hours to ensure the crop is harvested during the optimal time (Carrol, 2015). Table 3 shows that there were no significant differences ($P > 0.05$) in field time distribution for each task between *KDC* and *WS* at 5% significant level.

3.6. Harvesting time

Table 3 states that the mean harvesting time (excluding cornering, reversing, unloading, machine adjustment and setting) for both *KDC* and *WS* were 1.8 and 2.14 hr/ha, respectively. The *KDC* spent 11.03% lower harvesting time than the WS due to higher of FS and working width. Elsoragaby et al. (2019) reported that the mini combine harvester (*WS*) spent 1.36 hr/ha for harvesting operation in paddy field. Busato et al. (2007) mentioned that using combine harvester with 9 m working

Table 2. Comparison of field performance between two typical mini combine harvesters

Field performance	KDC (Mean ± SD)	WS (Mean ± SD)	Difference (%)	*p*-value
FS , km/hr	3.82 ± 0.51	3.13 ± 0.91	+ 22.04	0.34
EFC , ha/hr	0.28 ± 0.06	0.25 ± 0.05	+ 12.00	0.65
FE, %	50.00 ± 12.01	54.35 ± 16.11	- 8.00	0.65
FC, l/ha	16.85 ± 3.61	12.57 ± 2.19	- 34.05	0.20
FMI	0.84 ± 0.18	0.81 ± 0.17	+ 3.70	0.21

Table 3. Comparison of field time distribution between two typical mini combine harvesters

Task	Kubota DC 105X (Mean ± SD)	World Star 7.0Plus (Mean ± SD)	Difference, (%)	*p*-value
Harvesting, hr/ha	1.8 ± 0.41	2.14 ± 0.68	-15.89	0.31
Cornering and reversing, hr/ha	0.35 ± 0.02	0.50 ± 0.10	-30.00	0.09
Unloading, hr/ha	1.25 ± 0.32	1.21 ± 0.37	+3.31	0.58
Machine adjustment & setting	0.15 ± 0.04	0.14 ± 0.02	+7.14	0.20
Total, hr/ha	3.55 ± 1.01	3.99 ± 1.01	-11.03	0.61

width combine harvester spent 0.12 hr/ha in wheat harvesting. High variation (91.12 to 94.39%) in harvesting time spent between mini combine harvesters (*KDC* and *WS*) and conventional combine harvester (9 m working width) as previously stated is due to difference in machinery specifications. For instance, the mini combine harvester working width is 3 times shorter than conventional combine harvester which negatively affects the harvesting time of mini combine harvester (Elsoragaby et al., 2019).

3.7. Cornering and reversing time

Table 3 shows that the mean cornering and reversing time for *KDC* and *WS* were 0.35 and 0.5 hr/ha, respectively. *KDC* with 2.67 m of working width had 30% lower turning time spent than *WS* with 2.20 m of working width. Instead of harvesting time, the size of the working width also gives great influence in turning time. The bigger working width or wider equipment results in a smaller number of acres per hour thus reduce the number of turning during field operation and save a lot of working time (Hanna, 2016).

3.8. Unloading time

The time spent to unload the grain using *KDC* and *WS* was 1.25 and 1.21 hr/ha, respectively as shown in Table 3. It shows that *KDC* had 3.31% higher grain unloading time than *WS*. Two different varieties of rice (KDML 105 and PSL2) had 43.24% difference in unloading time using Thailand combine harvester (Doungpeng et al., 2018). Therefore, the value of unloading time normally varies according to the type of combine harvester, harvesting crops and standard management practices. The small difference in percentage (3.31%) of unloading time (Table 3) in the grain corn harvesting between *KDC* and *WS* is due to high consistency of standard management practice during grain unloading which required the machinery to unload the grain into the conveyed truck on site which was near to the harvesting plots. The difference in unloading time might be higher if the standard management practices of farm machinery are inconsistent during field operation which eventually affects the total field time.

3.9. Machine setting and adjustment

As shown in Table 3, the machine setting and adjustment time spent by *KDC* and *WS* were 0.15 and 0.14 hr/ha, respectively. *KDC* recorded 7.14% lower time spent for machine setting and adjustment than *WS*. An early study on Thailand combine harvester had indicated that the machine adjustment and setting consumed 0.10 and 0.13 hr/ha in rice harvesting with 2 different crop varieties (KDML105 and PSL2) (Doungpeng et al., 2018). Most of combine harvester such as *WS* was designed to suit the operation (cutting, separating and cleaning) with various type of crops such as rice, wheat, rapeseed, soybean and corn required specific setting and adjustment of the machine components due to different mechanical and physical properties of the crops. Therefore, high frequency of adjustment, setting and fine-tuning of the farm machinery due to lack of skills, knowledge and experience of operator could result to high time loss.

3.10. Total field time

Table 3 shows that the total field time spent for both *KDC* and *WS* were 3.55 and 3.99 hr/ha, respectively. *KDC* had 11.03% lower total field time than *WS*. Elsoragaby et al. (2019) revealed that the mean total field time which was derived from Eqs. 3 was equal to 1.9 hr/ha in paddy harvesting when using *WS*. In soybean harvesting, the total field time varied from 0.05 to 0.09 hr/ha due to differences in working width sizes (Hanna, 2016). The differences in field time between *KDC* and *WS* were dependent on the level of management practice consistency and the performance of the respective machinery according to the machine specification and design such as the recommended operating speed, length of the existing working width, and required machine adjustment and setting to suit with the physical properties of the harvesting grain crops (Al-Mitewty et al., 2019).

4. Conclusion

This study examined five parameters of field performance between two typical mini combine harvesters (*KDC* and *WS*) in grain corn harvesting. The mean value of field efficiency (FE), effective field capacity (EFC), fuel consumption (FC) and field machine index (FMI) of *KDC* were 50.00%, 0.28 ha/hr, 16.85 l/ha and 0.84, respectively. The mean value of FE, EFC, FC and FMI of *WS* were 54.35 %, 0.25 ha/hr, 12.57 l/ha and 0.81, respectively. *KDC* has 12% higher EFC, 8% lower FE and 34.05% higher FC than *WS*. *KDC* with 3.55 hr/ha of mean total field time has 11.03% lower field time than *WS*. Generally, the *WS* is more efficient than *KDC* in terms of FE and FC in grain corn harvesting.

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Author contributions

Mohamad Hairie Masroon: Carried out the literature review and performed the main writing part. Nazmi Mat Nawi & Azmi Yahya: Supported the study by giving their advice and providing the concept and structure of the manuscript. Mohamad Firdza Shukery: Supervised the project and verified the analytical method. Mohamed Ezzeldien Salih Amin: Reviewing and editing final manuscript.

Conflict of interests

The authors declare that they have no competing financial interest or personal relationships that could have appeared to influence the work reported in this paper.

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