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Evaluation of Field Performance and Energy Consumption of a Medium-sized Combine Harvester for Harvesting Glutinous Rice in Malaysia

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ABSTRACT

A medium-sized combine harvester has been recently deployed to harvest newly introduced high-value glutinous rice in Malaysia. Thus, efficient utilisation of combine harvesters during harvest is essential to minimise operating costs and grain loss. This study evaluated a medium-sized combine harvester's performance and energy consumption for harvesting glutinous rice. The experiment was carried out on a one-hectare paddy field with three sub-plots using a central composite design (CCD). A time-motion study was conducted during the harvesting operation to determine the combine harvester's performance parameters, which included field operating speed (FS), field efficiency (FE), theoretical field capacity (TFC), effective field capacity (EFC), grain throughput capacity (GTC), fuel consumption (FC) and field machine index (MI). The energy expended during the operation, which included machinery energy (ME), fuel energy (FCE), human energy (HE), and total energy (TE) input, were also computed. The average FS, FE, TFC, EFC, FC, and MI values were 2.42 km/h, 59.78%, 0.56 ha/h, 0.33 ha/h, 14.89 l/ha, and 0.30, respectively. The mean values of ME, FCE, HE, and TE were 305.35, 711.69, 3.62, and 1020.66 MJ/ha, respectively. The combine harvester achieved an average grain throughput capacity (GTC) of 1796.91 kg/h, demonstrating its effectiveness in handling glutinous rice harvesting. The average time

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distribution for the harvesting operation, such as effective harvesting time, turning/reversing time, and unloading time, was 1.85 h/ha, 0.38 h/ha, and 1.05 h/ha, respectively. Based on the results, it is concluded that the medium-sized combine harvester is technically and economically suitable for harvesting glutinous rice.

Keywords: Combine harvester, energy utilisation, glutinous rice, performances, time distribution

INTRODUCTION

Glutinous rice (*Oryza sativa var. glutinosa*) is one of Southeast Asia's most popular rice cultivars, especially in Thailand and Malaysia. Glutinous rice is different from typical white rice because it contains negligible amounts of amylose and high amounts of amylopectin, making the cultivar gluten-free (Sattaka, 2019). Glutinous rice is always in high demand, especially during festivals (Sattaka et al., 2020). Previously, Malaysia imported glutinous rice from Thailand, accounting for approximately 15% of the total 891,000 metric tonnes of rice imported into the country (Zainal & Shamsudin, 2021). Recently, due to strong demand, Malaysia has started planting two important local glutinous rice cultivars known as Susu and Siding in Langkawi, with cultivation areas around 14.76 ha and 24.2 ha, respectively (Zainal & Shamsudin, 2021).

Harvesting is a critical process that can affect rice production's quantity, quality, and cost. The use of a combine harvester is an effective way to reduce production costs and enhance labour productivity (Alizadeh & Allameh, 2013). Using a combine harvester is one of the most advanced mechanised harvesting technologies in Malaysian paddy production, and about 100% of rice harvesting in this country has been fully mechanised (Pebrian & Ismail, 2018). Rice harvesting in Malaysia has traditionally been carried out using a large combine harvester. However, this type of combine is becoming obsolete due to the age and insufficient machine parts. Wagiman et al. (2019) reported that using large combine harvesters could also lead to soil damage and hardpan formation due to compaction, especially when the soil is too wet during harvest. Recently, a medium-sized combine harvester has been introduced into the rice field as a cost-effective alternative to a large combine harvester. Therefore, optimising the working performance of the new medium-sized combine harvester is very important to maximise crop yield during harvesting while minimising operating costs at the optimal time and moisture level.

The field speed of the combine harvester is an important contributing factor to the harvest operation's efficiency. According to Hunt and Wilson (2016), the most critical aspect in optimising the performance of a combine harvester is field speed. Additionally, Jawalekar and Shelare (2020) stated that the machine's forward speed is the primary element affecting the combine harvester's performance. Mokhtor et al. (2020) reported that farmers' satisfaction with automated rice harvesting in Malaysian paddy fields was significantly affected by the field speed of the combine harvester. As a result, the field speed of the combine harvester is a major concern during mechanical harvesting. Thus, optimising the field speed and other factors such as cutting height, concave clearance, drum speed, fan speed and crop moisture content during harvest will minimise harvesting costs and reduce grain loss.

In addition, energy consumption and its efficiency are also important factors to be considered in managing agricultural machinery (Canakci et al., 2005). Efficiently utilising energy may improve rice production, profitability, sustainability, and industry competitiveness (Singh et al., 2004). Farmers who are able to identify and measure various energy sources involved in grain harvesting operations may be able to increase energy efficiency, thereby decreasing production costs (Masroon et al., 2020a).

In Malaysia, medium-sized combine harvesters have gained popularity in recent years for harvesting white rice. The machine has also been employed to harvest glutinous rice. However, despite the distinct differences in mechanical and physical properties, culinary uses, and cultural significance between glutinous and normal white rice, no research has been undertaken to quantify the field performance and energy consumption of a medium-sized combine harvester utilised for harvesting glutinous rice in a field. Therefore, this study aims to determine a medium-sized combine harvester's field performance and energy consumption when harvesting glutinous rice. The specific goals were to measure the theoretical field capacity, effective field capacity, field efficiency, the distribution of human, fuel, and machine energy, and time distribution during harvesting.

MATERIALS AND METHODS

Study Location

This research was conducted in a glutinous rice field in Ayer Hangat (06°25'14.7"N, 99°48'23.00"E), Langkawi Island, Malaysia. The weather data recorded during the operation included ambient temperature (33°C), humidity (83%), wind speed (5km/h) and atmospheric pressure (1008 Pa). These weather data were obtained using a real-time digital weather detection instrument (AcuRite 02077 colour weather station forecaster). The experiment was carried out on a one-hectare paddy field using a central composite design (CCD). The experimental plot was designed to have three plots; each plot accommodated ten random runs of the experiment for 30 runs throughout the experiment.

Rice Variety

The variety of glutinous rice planted by the farmers was Pulut Siding. In Malaysia, Pulut Siding variety is the most improved local variety which most farmers use. The rice was sown in November 2021 and harvested in March 2022. It reached maturity at 116 days after germination. The average crop's height at harvest was 0.85 m. During harvest, the rice had an average moisture content and yield of 19.50% and 5870 kg/ha, respectively.

Medium-size Combine Harvester

A medium-sized combine harvester (FM World Star; model WS 7.0 Plus) with a 2.3-meter cutting width and rated power of 108 hp at 2600 rpm was utilised in this study (Figure 1). This type of combine harvester is Malaysia's most recent model employed for paddy harvesting. The specifications of the combine harvester are presented in Table 1.

Figure 1. Typical medium-sized combine harvester for harvesting glutinous rice

Table 1
Technical specification of the medium-sized combine harvester

Parameters	Specifications
Model	WS 7.0 Plus++ (4G33-TC)
Overall Dimension (mm)	5150 × 2620 × 3030
Weight (kg)	3400
Power (kW/hp)	80.53/108
Rotational speed (rpm)	2600
Fuel tank capacity (lit)	130
Track type	Rubber track
Cutting width (m)	2.36
Feeding capacity (kg/s)	6
Threshing type	Axial flow, beater bar
Threshing cylinder (mm)	620 × 2010
Fan type	Centrifugal fan
Grain tank capacity (m^3)	1.7
Unloading discharge (kg/s)	1.68

Measurement of Parameters for Field Performance and Energy Consumption

Measurement of Harvesting Time. A stopwatch was used to record the time the combine harvester took to perform an individual task in each run during the harvesting experiment, including harvesting, turning, reversing, unloading the grain, refuelling, or adjusting the machine. The total field time represents when the combine harvester engine was turned on, run, and turned off once the job was completed (Olt et al., 2019). The data was used to compute the field performances, which included the forward speed (FS), effective field capacity (EFC), field efficiency (FE), and field machine index (FMI).

Determination of the Forward Speed. The range of the forward speeds reported in the previous studies and the rated engine speed of the medium-sized combine harvester used in this study were considered in determining the optimum forward speed. The field forward speed (FS) of the combine harvester was determined by measuring the distance travelled by the machine divided by the time taken to travel. It was determined from Equation 1 by Mokhtor et al. (2020).

$$FS = \frac{D}{t} \qquad [1]$$

Where FS represent the field speed of the machine (km/h), D is the distance travelled by the machine during the operation (km), and t is the time taken to cover the distance travelled (h).

Determination of the Theoretical Field Capacity. The theoretical field capacity (TFC) is the product of the field speed and the effective working width of the machine. It was obtained from Equation 2, reported by ASABE (2011).

$$TFC = \frac{W \times S}{10} \qquad [2]$$

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

Determination of the Effective Field Capacity. The effective field capacity (EFC) is the ability of the machine to harvest the crop under the actual field conditions (Masroon et al., 2020a). The EFC was determined as the area harvested by the machine divided by the total working time in the field (Elsoragaby et al., 2019). It was obtained using Equation 3.

$$EFC = \frac{A}{T} \qquad [3]$$

Where EFC represents the effective field capacity of the machine (ha/h), A is the area of the harvested plot (ha), and T is the total working time taken to harvest the plot (h).

Determination of the Field Efficiency. Field efficiency (FE) is the ratio between the combine harvester's productivity under actual working conditions and the theoretical maximum possible productivity (Elsoragaby et al., 2019). It describes how efficiently the time was spent to conduct the operation by the machine. It was determined by Equation 4, reported by ASABE (2011).

$$\mathrm{FE} = \frac{\mathrm{EFC}}{\mathrm{TFC}} \qquad [4]$$

Determination of the Fuel Consumption. The fuel consumption (FC) was recorded using a measuring cylinder of known volume by refilling the fuel tank to its full capacity after each run of harvesting tasks (ASABE, 2011).

Determination Of the Grain Throughput Capacity. The grain throughput capacity (GTC) of the combine harvester is a performance metric representing the amount of grain the machine can harvest and process over a specific area or time. It is measured in tons or kilograms per unit of area or time. The GTC of the combine harvester (kg/ha) was obtained using Equation 5, reported by Amponsah et al. (2017).

$$\mathrm{GTC} = \frac{10 \times \text{total weight of grain (g)}}{\text{Area covered in 30 m run (m}^2\text{)}} \qquad [5]$$

Equation 5 can be re-arranged to reflect an actual field operation, as shown in Equation 6.

$$\text{GTC (kg/h)} = \text{GTC (kg/ha) x Effective rate of harvesting (ha/h)} \qquad [6]$$

Determination of Energy Expenditure for Harvesting Operation

Energy expenditure during harvesting operation is a very important factor in evaluating the performance of the combine harvester. Understanding energy expenditure may help reduce energy loss and operation costs as much as possible, particularly during harvesting. The energy sources used during harvesting include machine, fuel, and human energy.

Machine Energy. Machine energy (ME) is an indirect energy assumed to be embodied in equipment during manufacturing (Elsoragaby et al., 2019). To measure the machinery energy, the machine's total useful life and EFC were considered (Muazu et al., 2014). The machine's weight was included by equally distributing it over the total economic life. It was determined using Equation 7 by Masroon et al. (2020a)

$$\mathrm{ME} = \frac{\mathrm{C_f} \times \mathrm{W}}{\mathrm{EFC} \times \mathrm{L}} \qquad [7]$$

Where ME is the machinery energy (MJ/ha), Cf is the energy conversion coefficient for the combine harvester, W is the weight of the combine harvester (kg), EFC is the effective field capacity (ha/h), and L is the economic life of the combine harvester (h). The machinery energy conversion factor used for the combine harvester was 87.63 MJ/kg (Masroon et al., 2020a).

Fuel Energy. Fuel energy (FCE) per unit area is a function of the fuel type and the amount of fuel the machinery consumes to power an engine when harvesting. FCE was calculated using Equation 8 (Masroon et al., 2020a).

$$\mathrm{FCE} = \frac{\mathrm{F_{con}} \times \mathrm{F_c}}{\mathrm{A}} \qquad [8]$$

Where FCE is the fuel energy (MJ/ha), Fcon is the quantity of fuel consumed (lit), Fc is the fuel energy conversion coefficient (MJ/lit), and A is the farm area covered (ha). The fuel energy conversion factor used for the combine harvester was 47.80 MJ/kg (Masroon et al., 2020a).

Human Energy. Human energy (HE) expenditure during the harvesting operation was evaluated based on the number of farm workers engaged in the harvesting operation per unit area and the time spent in performing the operation multiplied by an energy conversion coefficient. It was obtained from Equation 9 by Masroon et al. (2020a).

$$\mathrm{HE} = \frac{\mathrm{n} \times \mathrm{H} \times \mathrm{l_c}}{\mathrm{A}} \qquad [9]$$

Where HE is the human energy (MJ/ha), n is the number of workers engaged in the operation, H is the duration of the operation (h), lc is the energy conversion coefficient for human labour, and A is the farm area covered (ha). The human energy conversion factor used for the harvesting operation was 1.96 MJ/kg (Masroon et al., 2020a).

Total Energy Input. The total energy input (TEI) for the harvesting operation per hectare was calculated as the sum of all energy sources. It was calculated using Equation 10 (Elsoragaby et al., 2019).

$$\mathrm{TEI} = \mathrm{ME} + \mathrm{FCE} + \mathrm{HE} \qquad [10]$$

Mechanization Index. The percentage of machine energy expresses the mechanisation index (MI) to the sum of human, fuel, and machine energies. It was computed using Equation 11 by Elsoragaby et al. (2019).

$$\mathrm{MI} = \frac{\mathrm{ME}}{\mathrm{ME} + \mathrm{FCE} + \mathrm{HE}} \qquad [11]$$

Where MI is the mechanisation index, ME is the machinery energy (MJ/ha), FCE is the fuel consumption energy (MJ/ha), and HE is the human energy (MJ/ha).

Statistical Analysis

The study results were statistically evaluated using Design Expert Software (version 13.0.5.0) as a Central Composite Design with three experimental blocks, each comprising 10 replications. A one-way analysis of variance (ANOVA) was performed using the statistical analysis software (SAS) using the general linear model (GLM) method, and the mean results were compared for P-value with 95% confidence and a 5% significant level (0.05).

RESULTS AND DISCUSSION

Table 2 presents the results of the medium-sized combine harvester's performance in a glutinous rice field. The results show insignificant differences for each parameter at a 5% significance level ($P \leq 0.05$) between the harvesting plots. In addition, no mechanical or technical problems were observed during the machine's operation.

Field Speed and Theoretical Field Capacity

From Table 2, the average mean of FS and TFC of the medium-sized combine harvester was 2.42 km/h and 0.56 ha/h, respectively. Plot 3 had a higher FS value of 2.47 km/h than Plots 2 and 1, which have FS values of 2.38 km/h and 2.40 km/h, respectively, indicating that Plot 3 had 3.8 and 2.9% higher TFC than Plots 2 and 1, respectively. The result of FS in this study is lower than the results reported by Elsoragaby et al. (2019) and Masroon et al. (2020b) but higher than the result reported by Amponsah et al. (2017). It also agrees with the results reported by Masroon et al. (2020a), who also reported a moderate FS of 2.55 km/h and stated that when harvesting with a medium-sized combine harvester, a

Table 2
Performance of the medium-sized combine harvester during harvesting operation

Field Performance	Plot 1 (Mean ± SD)	Plot 2 (Mean ± SD)	Plot 3 (Mean ± SD)	Average (Mean ± SD)	P-Value
FS (km/h)	2.40±0.41	2.38±0.39	2.47±0.43	2.42±0.40	0.84
TFC (ha/h)	0.55±0.09	0.57±0.09	0.57±0.10	0.56±0.09	0.84
EFC (ha/h)	0.33±0.04	0.33±0.04	0.33±0.04	0.33±0.04	0.96
FE (%)	60.05±2.44	60.30±2.57	58.97±3.90	59.77±2.99	0.59
FC (l/ha)	15.61±2.00	14.78±1.63	14.28±1.41	14.89±1.68	0.69
GTC (kg/h)	1799.94±30.25	1798.88±35.40	1791.90±40.35	1796.91±35.33	0.75

Note. P-values for experimental parameters at a confidence level of 95% (n = 10). There were no significant differences in experimental parameters at 0.05

lower field speed should be used to avoid overloading the feeding rate thus reduce grain losses. Hamid et al. (2018) reported that a medium-sized combine harvester operated at a higher FS of 4.3 km/h would lead to a lower yield, while a lower FS of 2.25 km/h led to a higher yield. Inappropriate FS has the potential to reduce grain yield due to unpredictable losses. These results might be due to the high moisture level in the field at the time of the experiment because of the rainfall a few hours before harvest, which might have influenced the performance of the combine harvester. The optimum field speed was evaluated based on the quantity of grain harvester and fuel consumed by the combine harvester, with minimum grain loss.

Effective Field Capacity and Field Efficiency

The average mean of EFC and FE for the medium-sized combine harvester in glutinous rice fields were 0.33 ha/h and 59.77%, respectively (Table 2). Plot 2 had an average FE value of 60.30%, higher than Plots 1 and 3, which have average FE values of 60.05 and 58.97%, respectively. It indicates that the FE difference between the three experimental plots is insignificant. The EFC and FE values in this study are greater than those obtained by Masroon et al. (2020a) and Masroon et al. (2020b) but less than those obtained by Elsoragaby et al. (2019). It demonstrated that the medium-sized combine harvester investigated in this study was adequate to perform appropriately during the harvesting of glutinous rice. The operating distance covered by the machine during the operation was one of the elements that affected the efficiency of the harvesting performance. This study had a total working distance of 30 meters, which was longer than the distances reported in the previous studies with lower working distances (Amponsah et al., 2017; Elsoragaby et al., 2019; Masroon et al., 2020a, 2020b). The efficiency results obtained in this study may also be attributed to disparities in the settings of the operational parameters of the combine harvester and the swath covered by the machine. Such differences can lead to changes in the percentage of field efficiency, either by increasing or decreasing non-productive time.

Fuel Consumption

The average mean of FC for the medium-sized combine harvester employed in a glutinous rice field was 14.89 l/ha (Table 2). Plot 1 had a higher FC value of 15.61 l/ha than Plots 2 and 3, which have FC values of 14.78 l/ha and 14.28 l/ha, respectively, indicating that Plot 1 had 5.32% and 8.52% higher FC than Plots 2 and 3. Elsoragaby et al. (2019) and Masroon et al. (2020a) obtained 18.46 l/ha and 37.25 l/ha for fuel consumption, respectively, which are 60% and 19.34% higher than what was obtained in this study. It demonstrates that the performance of the medium-sized combine harvester on glutinous rice is adequate and cost-effective.

Grain Throughput Capacity

The average grain throughput of the combine harvester obtained in this study was 1796.91 kg/h at an effective machine operation of 0.33 ha/h (Table 2). The results show an insignificant difference between the plots, indicating that the performance of the combine harvester was consistent among the three plots. The average speed at which the combine harvester operated was relatively effective. The current operational setting of the combine harvester has allowed the machine to achieve a higher grain yield while maintaining grain quality and minimum losses. Therefore, farmers and operators need to consider the optimum setting of the combine harvester, crop conditions, and operator proficiency to maximise the grain throughput capacity.

Time Distribution for Harvesting Operation

Field time distribution is an essential performance parameter for analysing the combine harvester's effective time in the field. The field time distribution for harvesting glutinous rice includes the effective harvesting time, turning/reverse time, and unloading time, as presented in Table 3. The result shows insignificant differences at the 5% significance level ($P \leq 0.05$) between harvesting operations for each plot.

Effective Harvesting Time. Table 3 shows that the average effective harvesting time in glutinous rice fields utilising the medium-sized combine harvester was 1.85 h/ha. Plot 2 had a higher harvesting time value of 1.89 h/ha than Plots 1 and 3, which have harvesting time values of 1.86 h/ha and 1.81 h/ha, respectively. However, the difference in time between the three plots is negligible. The effective harvesting time is accounted for 56.40% of glutinous rice fields' total combine harvester operation time. Masroon et al. (2020a) and Masroon et al. (2020b) reported that the harvesting time of 2.14 h/ha and 2.68 h/ha, respectively, which are 13.55 and 30.97% greater than the harvesting time recorded in this study. In another study, Elsoragaby et al. (2019) obtained 1.36 h/ha, 26.50% less than the time recorded in this study. The differences in harvesting time

Table 3
Field time distribution for the harvesting operation

Operation	Plot 1 (Mean ± SD)	Plot 2 (Mean ± SD)	Plot 3 (Mean ± SD)	Average (Mean ± SD)	P-Value
Effective harvest (h/ha)	1.86 ±0.10	1.89±0.11	1.81±0.13	1.85±0.11	0.86
Turning-reverse (h/ha)	0.41±0.008	0.37±0.001	0.37±0.002	0.38±0.004	0.25
Unloading (h/ha)	104±0.004	1.04±0.002	1.05±0.001	1.05±0.002	0.76
Total (h/ha)	3.31±0.63	3.30±0.66	3.23±0.63	3.28±0.64	0.96

Note. P-values for experimental parameters at a confidence level of 95% (n = 10). There were no significant differences in experimental parameters at 0.05

between the combine harvesters were due to machinery specifications, terrain conditions, and the types and varieties of grain crops.

Turning/Reversing Time. The average mean for turning and reversal time in glutinous rice fields using the medium-sized combine harvester was 0.38 h/ha (Table 3). Plot 1 had a higher turning/reversing time of 0.41 h/ha than Plots 2 and 3, both of which had 0.37 h/ha—from the experiment, the time taken for turning/reversing of the machine accounted for 11.59% of the total harvesting operation time. By comparing the results obtained in this study with those of the existing studies, Masroon et al. (2020b) reported a turning/reversing time of 0.50 h/ha, equivalent to 12.53% of the total harvesting operation time, which is greater than the result of this study. In contrast, Elsoragaby et al. (2019) and Masroon et al. (2020a) reported 0.26 h/ha and 0.17 h/ha, respectively, equivalent to 5.98% and 8.95% of the total harvesting operation time, which is lower than the result obtained in this study. However, this study's result is reasonable compared to the results of the previous studies.

Unloading Time. According to Table 3, the average unloading time of glutinous rice utilising the medium-sized combine harvester was 1.05 h/ha, equivalent to 32.01% of the total harvesting operation time. When the findings of this study were compared to earlier findings, Elsoragaby et al. (2019) found that grain unloading accounted for 18.95% (0.36 h/ha) of total field time. Masroon et al. (2020) also reported that unloading the grain consumed 28.41% (1.24 h/ha) of the total field time. Masroon et al. (2020b) revealed that the time spent unloading grain utilising Kubota (KDS) and WordStar (WS) mid-size combine harvesters was 1.25 and 1.21 h/ha, respectively. Unloading time varies depending on the type of combine harvester, crop, and standard management practice. Inadequate or inconsistent farm machinery standard management practices during field operation reduce the total field time (Masroon et al., 2020b). The result of this study is higher than that reported by Elsoragaby et al. (2019) but lower than that reported by Masroon et al. (2020a) and Masroon et al. (2020b). It shows that the standard management procedures demonstrated in this study are appropriate and consistent.

Energy Inputs for Harvesting Glutinous Rice

Energy consumption is one of the most critical elements that must be monitored and analysed during field operation. Energy losses should be avoided to reduce operating costs, particularly during harvesting. Table 4 shows the energy consumption from three sources while harvesting glutinous rice with the medium-sized combine harvester. The results demonstrate insignificant variations across the three harvested plots.

Table 4
The energy input of harvesting operation for glutinous rice

Energy Input	Plot 1 (Mean ± SD)	Plot 2 (Mean ± SD)	Plot 3 (Mean ± SD)	Average (Mean ± SD)	P-Value
ME (MJ/ha)	305.83±40.96	307.45±39.92	302±44.05	305.34±41.64	0.97
FCE (MJ/ha)	746.1	706	682.36	713.68	-
HE (MJ/ha)	3.64±0.65	3.67±0.60	3.54±0.71	3.62±0.65	0.9
TE (MJ/ha)	1055.57±41.59	1017.73±40.50	988.68±44.73	1020.66±42.27	0.006
MI	0.29	0.3	0.31	0.3	-

Note. P-values for experimental parameters at a confidence level of 95% (n = 10). There were no significant differences in experimental parameters at 0.05

Machinery Energy. Table 4 shows that the average mean of machinery energy (ME) input for harvesting glutinous rice using the medium-sized combine harvester was 305.34 MJ/ha, equal to 29.73% of the total energy consumed during the harvesting operation. This study's findings are consistent with the 303.53 MJ/ha machinery energy input reported by Muazu et al. (2014). Elsoragaby et al. (2019) reported the machinery energy of 275.65 MJ/ha for harvesting wetland rice with a medium-size combine harvester, equivalent to 26.14% of the total energy input during the harvesting operation. Masroon et al. (2020a) also reported that 24.77% of machinery energy of the total energy utilised in the harvesting operation. This study indicates a higher machinery energy input than the previous studies due to differences in EFC, field and crop conditions, and operator expertise. Masroon et al. (2020a) revealed that harvesting operations with lower EFC values use more machinery energy than those with higher EFC values.

Fuel Energy. The average fuel energy (FCE) consumed for harvesting glutinous rice using the medium-sized combine harvester was 713.68 MJ/ha, as presented in Table 4. The energy consumed equals 69.92% of the total energy utilised during harvesting. Masroon et al. (2020a) recorded fuel energy consumption of 1780.70 MJ/ha for harvesting wetland rice with a medium size combine harvester. The value obtained was equivalent to 74.93% of the total energy input during the harvesting operation. According to a study by Amponsah et al. (2017), the fuel energy consumption was 882.39 MJ/ha, equivalent to 76.07% of the total energy input during the harvesting operation. Muazu et al. (2014) also reported that 853.54 MJ/ha of fuel energy, equivalent to 73.59% of the total energy utilised in harvesting wetland paddy. In this study, the fuel energy used by the medium-sized combine harvester is less than that obtained in the previous studies. It reveals that the fuel energy used is reasonable and economical.

Human Energy. The average value of human energy (HE) used in harvesting glutinous rice fields is 3.62 MJ/ha, equivalent to 0.35% of the total energy consumed during harvesting.

The percentage of human energy used in this study is consistent with the findings of (Masroon et al., 2020a). Elsoragaby et al. (2019) reported 0.23% human energy of total energy input during harvesting, similar to the amount obtained by Muazu et al. (2014). This study consumed more energy than previous studies due to a smaller harvested area and increased labour time per harvested area because of the lower EFC.

Total Energy. The average total energy (TE) consumed to harvest glutinous rice with the medium-sized combine harvester was 1020.66 MJ/ha. Muazu et al. (2014) and Elsoragaby et al. (2019) reported a total energy input of 1159.77 MJ/ha and 1160 MJ/ha for harvesting wetland paddy with medium-size combine harvesters, which is 12% greater than the energy expended in this study. Compared to other crop types, Masroon et al. (2020a) recorded a total energy input of 2376.96 MJ/ha for harvesting grain corn with a medium-sized combine harvester. The result yields an energy input that is 132.88 % greater than the energy utilised in this experiment. This study demonstrates a lower energy requirement for the harvesting operation, which is very desirable for harvesting contractors.

CONCLUSION

This study evaluated the field performance of the medium-sized combine harvester in harvesting glutinous rice. From the experiment, the average values of FS, FE, TFC, EFC, FC, and FMI were found to be 2.42 km/h, 59.78%, 0.56 ha/h, 0.33 ha/h, 14.89 l/ha, and 0.29, respectively. The average grain throughput capacity of the combine harvester was 1796.91 kg/h at an effective machine operation of 0.33 ha/h. The average time distribution for the harvesting operation, such as effective harvesting time, turning/reversing time, and unloading time, were 1.85 h/ha, 0.38 h/ha, and 1.05 h/ha, respectively. The mean values of ME, FCE, HE, and TE were 305.35 MJ/ha, 711.69 MJ/ha, 3.62 MJ/ha, and 1020.66 MJ/ha, respectively. Based on the findings of this study, the medium-sized combine harvester performed very well in the paddy field, as reflected by the field efficiency, grain throughput capacity, harvesting time, and energy consumption during harvesting. As a result, it can be concluded that the combine harvester is technically suitable for use in glutinous rice fields.

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