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Research Article

Performance Evaluation of Half-Feed Rice Combine Harvester

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Abstract: Rice (*Oryza sativa*) is one of the most important cereal grains cultivated on an area of 165 million hectares with approximately 756.7 million metric tons of production in the world. In 2019, Pakistan's area under rice cultivation was about 2.9 million hectares, with 7.5 million tons yield. Rice-wheat cropping system is the most famous, especially in Punjab, Pakistan. Harvesting is presently conducted through manual labor or with the utilization of outdated models of combine harvesters with huge grain quality and quantity losses. Imported half-feed rice combine harvester was introduced and an experiment was planned to evaluate its feasibility. The performance was evaluated at three levels of forward speed (3, 4, and 5 km/h) and cutter bar heights (12, 16, and 20cm) during the harvesting season of 2021 in the district Sheikhupura, Punjab. The machine performance was based on header loss, effective field capacity, broken grains percentage, fuel consumption, and field efficiency. The collected data was analyzed at a 5% level of probability by randomized complete block design (RCBD). The statistical analysis revealed that the machine performed better at the speed S_2 (4 km/h) and cutter bar height H_2 (16cm) with the maximum EFC (0.55 ha/h) and Field Efficiency (75.3%) as well as minimum Grain Losses (24.7 kg/ha) and Grain Breakage (14.2 kg/ha) in standing crop condition. Therefore, this machine is recommended to farmers due to its higher EFC and Field Efficiency as well as lower Grain Losses and Grain Breakage as compared to the conventional methods and obsolete machinery.

Keywords: Combine Harvester, Effective Field Capacity, Field Efficiency, Fuel Consumption, Header Loss.

1. INTRODUCTİON

Rice (*Oryza sativa*) is an important staple food for more than 50% population of the world. It accounts for 15% and 21% of human protein production and collective human calories per capita worldwide [1]. It is an important cash crop in Pakistan, contributing significantly to the country's total economy. It contributes 0.7% of GDP and 2.7% to agriculture. It is Pakistan's second biggest food grain product, and in recent years, it has become a significant source of international exchange reserves. Overall grain production in Pakistan is estimated to be 34 million tons, which exceeded about 33.3 million from the previous year [2]. In the Punjab province of Pakistan, the area between the Ravi and Chenab rivers is famous for rice production and Basmati rice is famous for its aroma all over the world having a huge customer demand. For the year 2021-22, Lahore Division produced a record 5.7 million tons of rice, both basmati and non-basmati, compared to a target of 4.4 million ton, as well as a 1.9% increase in per acre yield over the previous year [3].

Rice-wheat cropping system in Pakistan encompasses 2.1 million hectares, approximately three-fifths of which lies in the Punjab province. Punjab's rice-wheat region comprises districts of Gujranwala, Sheikhupura, and Sialkot. In the rice-wheat cropping system, there is very less time between rice harvesting and wheat sowing. Depending on the time of harvest of the rice crop, wheat conventional tillage requires pre-sowing irrigation on well-drained soils or draining or drying of soil in lowlands followed by one or

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two disking, two harrowing, and leveling that must be required on time. Late harvesting results in a decrease in the yield of wheat [4].

Delayed rice harvesting results in significant grain and straw losses attributable to over maturity, causing grain breakage as well as delays in seedbed preparation and planting operations [5]. Due to a labor shortage during peak harvest season, farmers are forced to postpone harvesting, resulting in substantial postharvest losses and, in some cases, crop loss due to natural disasters. The demand for agricultural labor has increased dramatically as planting intensity and production of crops have increased [6].

Manual harvesting has been a common practice in the region of South East Asia. Combine harvesters have become an attractive option in many locations in South East Asia as the increased labor cost. This mechanized method consumes less time as compared to manual harvesting, containing; cutting, collecting, sun-drying in the field, and carrying dried paddy to a threshing service. The use of a combine harvester reduces the cost of production and increases the profit. This method also helped reduce the labor shortage and improved rice grain quality [7].

Rice is harvested manually or with the help of combine harvesters. Currently, old models of combine harvesters are being used. These machines are outdated with huge grain quality and quantity losses. To overcome these losses imported half-feed rice combine harvesters were introduced into the rice-wheat cropping system. Keeping in view the above-mentioned problem an experiment was designed to test the feasibility of half-feed rice combine harvester at three different speeds, cutter bar heights and crop conditions.

2. MATERIALS AND METHODS

To retrieve useful information for the farmers of the Rice-Wheat cropping system and to examine the feasibility of the imported machine (Half-Feed Rice Combine Harvester) an experiment was conducted during the rice harvesting season in 2021 at Fatehpur, district Sheikhupura. The average temperature of the experimental area is around 22 °C in the month of October–November and it typically receives about 23.04 millimeters of precipitation and has 49.28 rainy days (13.5% of the time) annually.

2.1. Machine Specifications

The machine specifications are given in Table 1.

Table 1. Machine Specifications of Half-Feed Rice Combine Harvester.

Half-Feed Rice Combine Harvester	
Model name	ER112
Power hp	112 HP
Cutter bar width	7 FT.
Grain tank capacity	800 KG
Fuel tank capacity	85 L

2.2. Experimental Treatments

The performance of the machine was evaluated at three levels of forward speed (S_1 = 3 km/h, S_2 = 4 km/h, and S_3 = 5 km/h) and at three different cutter bar heights (12 cm, 16 cm, and 20 cm).

2.3. Machine Parameters/Performance Indicators

The performance indicators were header loss, effective field capacity, broken grains percentage, fuel consumption, operational time, and field efficiency.

2.3.1. Operational time

The operational time was recorded with the help of a stopwatch. The literature review indicated that this method was previously adopted [8] in which a stopwatch was used to record the amount of time spent on harvesting. The starting and stopping timings were included in the times recorded. The time wasted on turning the combine harvester was also recorded to calculate time losses.

2.3.2. Fuel consumption

Prior to the harvesting operation, the combine harvester was completely refueled. The quantification of fuel consumption was done by gauging the variance in the fuel levels within the tank before and after the operation.

2.3.3. Field efficiency

The field efficiency (FE) of a machine is the ratio of effective field capacity and theoretical field capacity. The FE for a real field procedure was never 100% due to headland turns, machine difficulties, ground surface, and overlapping [9].

The following formula was used to calculate FE:

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

Where,
FE = field efficiency (%)
EFC = effective field capacity (ha/hr)
TFC = theoretical filed capacity (ha/hr)

2.3.4. Adjustment of forward speed

The combine harvester was operated at three different speeds. The speed of the machine was measured by fixing a distance of 20 m and a stopwatch and a measuring tape. A stopwatch was used to record the time to cover the 20 m distance. The average forward speed was estimated using the formula after this operation was conducted three times [10].

$$Speed = \frac{Driven\ Length}{Driven\ Time\ Period} \quad (2)$$

2.3.5. Adjustment of cutter bar height

As per the treatments, the cutter bar heights were set at 12, 16, and 20 cm from the ground in plots consisting of Standing, Lodged, and Standing Cum Lodged Crops. The data was recorded three times in each treatment [11].

2.3.6. Grain losses

The method of measurement of Grain Losses includes the collection of all the grains that were left when the machine operates to harvest in a specific area. Combine harvester operation on an area of 1 m^2 with three replications was selected to calculate the grain losses [12].

Grain losses were found by the following formula,

$$GL = 4047m^2 \times W_L \quad (3)$$

Where,
GL = grain losses
W_L = Weight of lost grains in 1m^2 area
1 acre = 4047 m^2

2.3.7. Damaged grain (%)

Three grains samples of weight 250 g from each treatment were collected. These samples were collected from the grain tank of the combine harvester and each sample was representative of 3 plots. To measure grain damage percentage weight of samples and the weight of broken grain were recorded separately as in previous research [13]. The grain damage percentage was recorded below,

$$GD = \frac{WD}{WS} \times 100 \quad (4)$$

Where,
GD - grain damage (%)
WD – the weight of damaged grain
WS – the weight of the sample

2.4. Statistical Analysis

The experimental data was statistically analyzed by using Randomized Complete Block Design (RCBD) within the "Statistix 8.1" software, applying a significance level of 5%.

3. RESULTS AND DISCUSSION

The performance of the Half-Feed Rice Combine Harvester was evaluated in terms of effective field capacity, field efficiency, grain losses in the field, and grain breakage at three forward speeds and three cutter bar heights. Results for various parameters concerning different treatments are discussed as follows.

3.1. Theoretical Field Capacity (TFC)

TFC of Half-Feed Rice Combine Harvester was measured in standing, standing cum lodged, and lodged crops during the wheat harvesting season of 2022. At speeds, S_1, S_2, and S_3, TFC was measured to be 0.64 ha/h, 0.84 ha/h, and 1.05 ha/h [13].

3.2. Effective Field Capacity (EFC)

In standing crop, statistical analysis has shown that maximum effective field capacity (0.55 ha/hr) was achieved at speed S_3 (5 km/h) and cutter bar height H_3 (20 cm), whereas the lowest field capacity

Table 2. Effect of different Forward Speeds with different Cutter Bar Heights on EFC in Standing Crop.

Speed	H_1	H_2	H_3	Mean
S_1	0.36 c	0.36 c	0.34 c	0.35 c
S_2	0.44 b	0.43 b	0.48 b	0.45 b
S_3	0.52 a	0.53 a	0.55 a	0.53 a
Mean	0.41 a	0.44 a	0.45 a	

*Mean with the same letters are statistically non-significant at a 5% level of probability.

(0.34 ha/hr) was achieved at speed S_1 (3 km/h) and cutter bar height H_3 (20 cm) as shown in Table 2. The statistical results have shown that the mean EFC at different speeds was significantly different while it was non-significantly different at different cutter bar heights at a 5% level of probability. The findings of the current experiment are parallel with the results of [14] who found that the EFC of a Half-Feed Rice Combine Harvester increases from 0.35 to 0.56 ha/hr as speed increases from 3km/h to 5 km/h respectively.

In standing cum lodged crop, statistical analysis showed that maximum EFC (0.52 ha/hr) was observed at speed S_3 (5 km/h) and cutter bar height H_2 (16 cm), and minimum EFC (0.30 ha/hr) was observed and speed S_1 (3 km/h) and cutter bar height H_2 (16 cm) respectively as shown in Table 3. The statistical results have shown that the mean EFC at different speeds was significantly different while it was non-significantly different at different cutter bar heights at a 5% level of probability. The findings of the current experiment are similar to the findings of [14] who suggested that the EFC of a Half-Feed Rice Combine Harvester increases from 0.35 ha/hr to 0.56 ha/hr with an increase in speed from 3 km/h to 5 km/h, respectively.

In lodged crop, statistical analysis has shown that maximum EFC (0.49 ha/hr) was observed at speed S_3 (5 km/h) and cutter bar height H_1 (12 cm) while minimum EFC (0.29 ha/hr) was observed at speed S_1 (3 km/h) and cutter bar height H_2 (16 cm) respectively. The statistical results have shown that the mean EFC at different speeds was significantly different while it was non-significant at different cutter bar heights. The findings of this experiment are more or less similar to the outcomes of [14] who found that the EFC of a Half-Feed Rice Combine Harvester increases from 0.35 ha/hr to 0.56 ha/hr with the increase in speed from 3 km/h to 5 km/h respectively.

Table 3. Effect of different Forward Speeds with different Cutter Bar Heights on EFC in Standing Cum Lodged Crop.

Speed	H_1	H_2	H_3	Mean
S_1	0.32 c	0.30 c	0.33 c	0.31 c
S_2	0.45 b	0.48 b	0.47 b	0.46 b
S_3	0.51 a	0.52 a	0.49 a	0.51 a
Mean	0.44 a	0.45 a	0.41 a	

*Mean with similar alphabets are non-significant statistically at a 5% level of probability.

Table 4. Effect of different Forward Speeds with different Cutter Bar Heights on EFC in Lodged Crop.

Speed	H_1	H_2	H_3	Mean
S_1	0.30 a	0.29 c	0.31 c	0.31 c
S_2	0.35 c	0.37 b	0.39 b	0.37 b
S_3	0.49 a	0.47 a	0.45 a	0.47 a
Mean	0.37 a	0.36 a	0.36 a	

*Similar letters with means are statistically non-significant at a probability level of 5%.

3.3. Field Efficiency

In standing crop, statistical results have shown that maximum field efficiency (75.3%) was observed at speed S_2 (4 km/h) and cutter bar height H_2 (16 cm) whereas the lowest field efficiency (67.6%) was observed at speed S_1 (3 km/h) and cutter bar height H_2 (16 cm) as shown in Table 4. The mean value of field efficiency was significantly different at different cutter bar heights while there was a non-significant difference at different speeds at a 5% level of probability. The findings of the current experiment are parallel with the findings of [15] who found that the Field Efficiency of a Half-Feed Rice Combine Harvester increases from 66% to 74% as speed increases from 3 km/h to 5 km/h, respectively.

Table 5. Effect of Different Forward Speeds with Different Cutter Bar Heights on Field Efficiency in Standing Crop.

Speed	H_1	H_2	H_3	Mean
S_1	70.7 b	67.6 b	71.6 b	69.2 a
S_2	74.3 a	75.3 a	73.8 a	74.2 a
S_3	71.5 ab	72.7 b	74.0 a	72.1 a
Mean	72.1 c	71.8 a	72.7 b	

Table 6. Effect of Different Forward Speeds with Different Cutter Bar Heights on Field Efficiency in Standing Cum Lodged Crop.

Speed	H_1	H_2	H_3	Mean
S_1	67.9 a	62.5 b	66.5 a	69.8 a
S_2	71.8 b	73.3 a	71.3 b	68.8 b
S_3	69.9 a	70.7 a	69.5 a	69.1 a
Mean	65.6 a	72.1 a	70.4 a	

In standing cum lodged crop, statistical results have shown that maximum field efficiency (73.3%) was achieved at speed S_2 (4 km/h) and cutter bar height H_2 (16 cm) whereas the lowest field efficiency (62.5%) was observed at speed S_1 (3 km/h) a cutter bar height H_2 (16 cm). The statistical analysis has shown that the mean value of field efficiency there was a non-significant difference for cutter bar height. The mean findings for field efficiency at different speeds are significantly different at (S_1 and S_2) and (S_2 and S_3) while they are non-significantly different at (S_1 and S_3). The findings of the current experiment are more or less similar to the results of [15] who suggested that the Field Efficiency of a Half-Feed Rice Combine Harvester, increases from 66% to 74% as speed increases from 3 km/h to 5 km/h, respectively.

In lodged crop, statistical results have shown that maximum field efficiency (67.1%) was achieved at speed S_3 (5 km/h) and cutter bar height H_1 (12 cm) whereas the lowest field efficiency (57.7%) was observed at speed S_1 (3 km/h) and cutter bar height H_2 (16 cm). The statistical analysis has shown that the mean-field efficiency was significantly different at different speeds; however, there was a non-significant difference at different cutter bar heights at a 5% level of probability. The results were similar to the findings of [15] who observed that the Field Efficiency of a Half-Feed Rice Combine Harvester increases from 66% to 74% as speed increases from 3 km/h to 5 km/h, respectively.

Table 7. Effect of Different Forward Speeds with Different Cutter Bar Heights on Field Efficiency in Lodged Crop.

Speed	H_1	H_2	H_3	Mean
S_1	61.8 b	57.7 b	59.1 b	59.5 b
S_2	64.8 c	64.2 c	66.3 a	62.9 c
S_3	67.1 a	66.6 a	66.3 a	66.9 a
Mean	69.5 a	65.1 a	66.6 a	

3.4. Grain Losses

In standing crop, maximum Grain Losses (42.5 kg/ha) occurred when the machine was operating at S_3 (5 km/h) and cutter bar height H_3 (20 cm), whereas the minimum grain losses (25.2 kg/ha) occurred at S_1 (3 km/h) and cutter bar height at H_2 (16 cm) as shown in Table 8.

The mean results for grain losses were significantly different at different speeds while they were non-significantly different for different cutter bar heights at a 5% level of probability. The findings of the current experiment are similar to the findings of a previous study [13] in which Grain Losses for Half-Feed Rice Combine Harvester increased from 25.5 kg/ha to 39.8 kg/ha with the increase in speed from 3 km/h to 5 km/h, respectively.

In standing cum lodged crop, maximum Grain Losses (45.4 kg/ha) occurred when the machine was operating at speed S_3 (5 km/h) and cutter bar height H_3 (20 cm) whereas the minimum Grain Losses (24.7 kg/ha) occurred at speed S_2 (4 km/h) and cutter bar height (H_2) as shown in Table 9. The mean Grain Losses of the machine were at significant differences at different speeds while there was a non-significant difference with respect to different cutter bar heights at a 5% level of probability. The findings of the current experiment are less or more similar to the results of [13] who found that Grain Losses for Half-Feed Rice Combine Harvester increased from 25.5kg/ha to 39.8kg/ha with the increase in speed from 3 km/h to 5 km/h, respectively.

In lodged crop, maximum Grain Losses (47.6 kg/ha) occurred when the machine was operating at S_3 (5 km/h) and cutter bar height H_3 (20 cm) whereas the minimum grain losses (27.9 kg/ha) occurred when the machine operates at speed S_2 (4 km/h) and cutter bar height H_2 (16 cm) as shown in Table 10. The mean results for Grain Losses

Table 8. Effect of different Forward Speeds with different Cutter Bar Heights on Grain Losses in Standing Crop.

Speed	H_1	H_2	H_3	Mean
S_1	29.5 b	25.2 b	26.4 c	31.1 b
S_2	25.3 c	23.7 c	33.3 b	26.7 c
S_3	38.3 a	31.2 a	42.5 a	34.1 a
Mean	27.1 b	27.4 b	37.3 a	

Table 9. Effect of different Forward Speeds with different Cutter Bar Heights on Grain Losses in Standing Cum Lodged Crop.

Speed	H_1	H_2	H_3	Mean
S_1	31.4 b	27.2 b	29.0 b	32.9 b
S_2	28.2 c	24.7 c	35.5 c	28.5 c
S_3	39.1 a	33.5 a	45.4 a	36.6 a
Mean	29.2 b	29.5 b	39.3 b	

of the machine were at a significant difference at different speeds while there was a non-significant difference with respect to different cutter bar heights at a 5% level of probability. The findings of the current experiment are parallel to the outcomes of Bawatharani *et al*. [13] in that Grain Losses for Half-Feed Rice Combine Harvester increased from 25.5kg/ha to 39.8kg/ha with an increase in speed from 3 km/h to 5 km/h, respectively.

3.5. Grain Breakage

In standing crop, maximum Grain Breakage (16.3 kg/ha) was observed at speed S_3 (5 km/h) and cutter bar height H_3 (20 cm) whereas the minimum grain breakage (14.2 kg/ha) was found at speed S_2 (4 km/h) and cutter bar height H_2 (16 cm) as shown in Table 11. The mean results of Grain Breakage were at a significant difference at speeds S_1 and S_3 and S_2 and S_3 while there was a non-significant difference at S_1 and S_2. The mean results for Grain Breakage with respect to cuter bar height were non-significantly different at a 5% level of probability. The findings of the current experiment are alike to the conclusions of Da *et al*. [16] who revealed that grain breakage for the machine increased from 13.1 kg/ha to 17.8 kg/ha as the speed increased from 4 km/h to 5 km/h, respectively.

In standing cum lodged crop, maximum grain breakage (16.1 kg/ha) occurred at speed S_3 (5 km/h) and cutter bar height H_3 (20 cm), whereas

Table 10. Effect of different Forward Speeds with different Cutter Bar Heights on Grain Losses in Lodged Crop.

Speed	H_1	H_2	H_3	Mean
S_1	35.1 b	30.2 b	32.1 b	36.7 b
S_2	32.2 c	27.9 c	38.9 c	31.7 c
S_3	43.2 a	37.1 a	47.6 a	39.5 a
Mean	32.4 b	32.9 b	42.6 b	

Table 11. Effect of different Forward Speeds with different Cutter Bar Heights on Grain Breakage in Standing Crop.

Speed	H_1	H_2	H_3	Mean
S_1	14.5 b	14.4 b	14.5 b	14.9 b
S_2	14.5 b	14.2 b	15.2 b	14.5 b
S_3	15.6 a	14.9 b	16.3 a	15.3 a
Mean	14.5 b	14.7 b	15.6 b	

the minimum grain breakage (14.3 kg/ha) was observed at speed S_2 (4 km/h) and cutter bar height H_2 (16 cm) as shown in Table 12. The mean results for Grain Breakage were at a significant difference at different speeds while there was a non-significant difference with respect to different cutter bar heights at a 5% level of probability. The findings of the current experiment are parallel with the findings of Da *et al*. [16] who observed that Grain Breakage for a Half-Feed Rice Combine Harvester increased from 13.1 kg/ha to 17.8 kg/ha as the speed increased from 4 km/h to 5 km/h, respectively.

In lodged crop, maximum Grain Breakage (16.5 kg/ha) was observed at speed S_3 (5 km/h) and cutter bar height H_3 (20 cm), whereas the minimum grain breakage (14.6 kg/ha) occurred at speed S_2 (4 km/h) and cutter bar height H_2 (16 cm) as shown in Table 13.

The mean results for Grain Breakage were at a significant difference at speed S_1 and S_2 or S_2 and S_3 while there was a non-significant difference at

Table 12. Effect of different Forward Speeds with different Cutter Bar Heights on Grain Breakage in Standing Cum Lodged Crop.

Speed	H_1	H_2	H_3	Mean
S_1	15.1 c	14.6 b	14.6 b	15.1 c
S_2	14.7 b	14.3 b	15.1 b	14.7 b
S_3	15.6 a	15.1 b	16.1 a	15.3 a
Mean	14.8 b	14.7 b	15.6 b	

Table 13. Effect of different Forward Speeds with different Cutter Bar Heights on Grain Breakage in Lodged Crop.

Speed	H_1	H_2	H_3	Mean
S_1	15.2 ab	14.8 a	15.1 b	15.3 a
S_2	15.1 b	14.6 a	15.2 b	14.9 b
S_3	15.7 a	15.2 a	16.5 a	15.6 a
Mean	15.1 b	14.9 b	15.8 a	

S_1 and S_3 at a 5% level of probability. The mean results for Grain Breakage were non-significantly different with respect to cutter bar heights at a 5% level of probability. The results of the current experiment are similar to the results of Da *et al*. [16] in which Grain Breakage for Half-Feed Rice Combine Harvester increased from 13.1 kg/ha to 17.8 kg/ha as the speed increased from 4 km/h to 5 km/h, respectively.

4. CONCLUSIONS

For Standing Crops, the maximum values for EFC and Field Efficiency were calculated as 0.55 ha/h and 75.3% at (S_2 and H_2), respectively. The minimum grain losses were observed as 24.7 kg/ha at (S_1 and H_2) and minimum grain breakage was recorded 14.2 kg/ha at (S_2 and H_2) respectively. For Standing Cum Lodged Crop, the maximum values for EFC and Field Efficiency were measured as 0.52 ha/h at (S_3 and H_2), 73.3% at (S_2 and H_2), respectively. The minimum grain losses were recorded as 25.2 kg/ha per hectare at (S_2 and H_2) and minimum grain breakage was observed 14.6 kg/ha at (S_2 and H_2) respectively. For Lodged Crop, the maximum values for EFC and Field Efficiency were found to be 0.49 ha/h at (S_3 and H_1) and 67.1% at (S_2 and H_2), respectively. The minimum grain losses were calculated as 27.9 kg/ha at (S_3 and H_3) and minimum grain breakage was measured as 14.6 kg/ha at (S_2 and H_2). Experimental results have shown that comparatively better performance was observed at forward speed (S_2 = 4 kmh^{-1}) and cutter bar height (H_2 = 16 cm) with maximum efficiency and minimum losses.

Overall machine worked better at speed S_2 (4 km/h) as compared to speed S_1 (3 km/h) and speed S_3 (5 km/h) (Figure 1), and crop with standing condition as considering field efficiency (%), grain losses (kg/ha) and grain breakage (kg/ha) as key performance indicators.

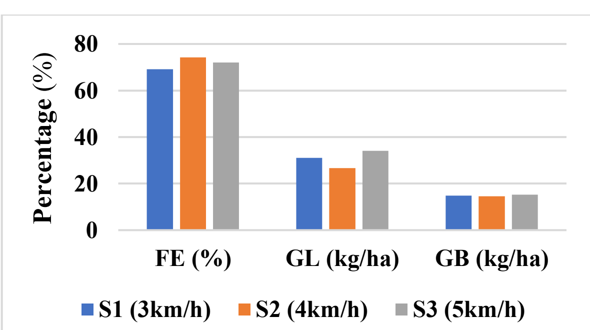

Fig. 1. Abstract Graph of Machine Performance Indicators.

5. FUTURE RECOMMENDATIONS

The performance of this machine can be tested for various rice varieties in different rice growing zones. This machine can also be tested for different soil types and various farm sizes. A knotting unit may be attached at the straw outlet for collecting them in bundles.

6. CONFLICT OF INTEREST

The authors declare no conflict of interest.

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