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Assessment of BRRI Whole Feed Combine Harvester (Model BRRI WCH2021) for Mechanized Rice Harvesting in Bangladesh

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Abstract

Agricultural mechanization plays a pivotal role in the transition from subsistence to commercial agriculture, with a particular focus on labour-intensive activities like harvesting. This study assesses the operational characteristics of the BRRI Whole Feed Combine Harvester (Model BRRI WCH2021) at the field level. Developed under the SFMRA project, the harvester's technical performance and loss assessment were conducted during the Boro 2022 and Aman 2022 seasons in farmer fields in Bangladesh's Rangpur region. The field efficiency of the harvester was determined to be 62.5% and 57.9% in the Boro and Aman seasons, respectively. Fuel consumption rates were recorded at 2.77 l/ha and 2.31 l/ha for the Boro and Aman seasons. The total harvesting losses, encompassing cutter bar, shatter, cylinder, and separation loss, averaged 0.56% and 0.48% in the Boro and Aman seasons, respectively. Mechanized harvesting with the BRRI Whole Feed Combine Harvester significantly reduced paddy losses by 5.81% compared to manual methods. The field evaluation results indicate the combine harvester's satisfactory performance, highlighting its potential to alleviate labour demands during peak harvesting. The development of the BRRI WCH offers a sustainable solution for rice harvesting mechanization among progressive farmers. It paves the way for the broader adoption of advanced agricultural technology in Bangladesh.

Keywords

BRRI Whole Feed Combine Harvester, Field Efficiency, Fuel Consumption, Harvesting Loss

1. Introduction

Bangladesh, with a population of approximately 170 million, relies heavily on agriculture, with about 45% of its workforce engaged in this sector. Rice (*Oryza sativa* L.) is the predominant crop, cultivated across 80% of the total cropped area in the country [1]. Projections indicate that the demand for rice will surge to 44.6 million tons by 2050 [2]. As the third-largest rice-producing nation, Bangladesh has successfully attained self-sufficiency in rice production [3]. The timely harvesting of rice is crucial for achieving optimal yields, but the scarcity of labor and escalating wages during peak periods pose significant challenges [4]. In this context, mechanization, mainly modern agricultural machinery like combine harvesters, plays a pivotal role. These machines are known for their efficiency, cost-effectiveness, and reduced labor requirements [5]. They enhance grain recovery by minimizing losses during harvesting, threshing, and cleaning.

In Bangladesh, the dominance of a rice-based cropping pattern is evident, driven by the high demand for rice as a staple food and the favourable conditions for rice cultivation [6]. However, significant rice losses occur in the production chain-harvest, processing, or storage [7]. Among these production activities, harvesting is vital to creating huge postharvest losses. Addressing these losses is crucial in meeting the growing demand for food in an increasingly populous world. Recently, farmers in Bangladesh have struggled with a pressing issue: labour scarcity for paddy harvesting. This shortage and escalating wages during peak work periods lead to delayed harvesting operations and a subsequent increase in grain and panicle shattering, resulting in significant losses [7] [8]. Manual rice harvesting is undoubtedly a cumbersome, time-intensive, and costly endeavour, requiring approximately 100 - 150 labor hours to harvest a single hectare of paddy field [9]. This exacerbates labor shortages during the peak farming seasons and leads to quantitative and qualitative losses in rice yield.

To address this challenge, combine harvesters offer a mechanized solution to address these challenges, promising reduced production costs and a boost in labor productivity [8]. The combine harvester stands out as a vital solution to address the shortage of manual labor in paddy harvesting, fulfilling the pressing need for a swift and efficient method in Bangladesh [10]. This mechanized approach boasts higher operational efficiency, significantly reduced labor requirements, and notable time savings compared to separate harvesting. However, these machines are complex and expensive, and their successful operation requires a field of sufficient size and even terrain, along with skilled technicians for maintenance and management. Various factors contribute to the performance of combine harvesters, falling into two categories: machine-related and plant-related factors. Among the latter, variables such as rice variety, moisture content, and degree of maturity hold particular significance in determining overall effectiveness. Despite these challenges, the adoption of combine harvesters in Bangladesh is becoming increasingly urgent, given the shortage of manual labor and the need to reduce harvesting lose. Furthermore, combine harvesters offer several other benefits, such as increased cropping intensity, amplified crop productivity, and enhanced economic empowerment.

The swift adoption of modern mechanical harvesting techniques, including the use of combine harvesters, mini-combine harvesters, and reapers, has become an urgent imperative [11]. These practices substantially reduce time, labor, and financial expenditure, while concurrently alleviating human toil and curbing harvesting losses. Additionally, they contribute to heightened cropping intensity, amplify crop productivity, and ultimately foster economic empowerment. An illustrative example underscores this transformation: traditional methods involving manual harvesting and mechanical threshing by laborers, demanded approximately 20 hours to complete the operation. In stark contrast, the utilization of combine harvesters and straw reapers reduced this timeframe drastically to just 3.5 hours (Anonymous, 2014). Furthermore, Zhang Jun [12] conducted a study revealing that the operational efficiency of a combine harvester in rapeseed crops surpassed manual harvesting by an astonishing factor of 50. This stark contrast underscores the immense benefits of modern mechanized harvesting methods.

Harvesting machinery can generally be categorized into three types: reapers, mini-combines, and combine harvesters, all utilized worldwide. However, in many developing nations, such as Bangladesh, manual harvesting remains prevalent due to the limited availability of modern technology. When evaluating any harvesting machine's technical and economic performance, a pivotal factor is the area it can cover within a given time. According to manufacturers' specifications, combine harvesters outperform reapers, mini-combines, and manual harvesting regarding area coverage per unit time. The advent of combine harvesters is one of the most significant labor-saving innovations in agriculture, markedly reducing the proportion of the population engaged in agricultural activities.

Several studies have been conducted on combining harvesters' work [13]. According to Islam, Alam [14], these machines represent an effective, cost-efficient, labor-saving technology, although their initial investment can be substantial. Several factors come into play when determining the profitability of harvester operation, including land size, machine accessibility, field-to-field distance, crop characteristics, soil and weather conditions, operational readiness and management practices, and financial considerations [15]. The harvesting field's size, shape, and layout notably impact the overall performance of the combine harvester during operation, as highlighted by Huda Nath [5]. Additionally, Islam, Islam [16] recommends operating the farm machine lengthwise to minimize turning events, which tend to prolong the loss time of the harvester. In addition, research conducted by Hossain, and Hoque [17] further underscored the advantages of using combine harvesters over manual methods, demonstrating notable reductions in average time, cost, and grain loss at 97.50%, 35.00%, and 2.75%, respectively. This study aims to evaluate both the technical and economic performances of combine harvesters and to analyze the benefits of a mechanical harvesting system compared to manual methods. The research will assess field performance parameters, including field capacity, field efficiency, time distribution, and harvesting costs, across different land sizes in the Rangpur region of Bangladesh.

2. Materials and Methodology

2.1. Study Location and Crop Conditions

The field trial took place in Mithapukur upazila, situated in the Rangpur District. This area is positioned between 25˚26' and 25˚41' north latitudes and between 89˚06' and 89˚27' east longitudes, as depicted in **Figure 1**. The crop's condition, including parameters such as plant height, plant-to-plant distance, plant density, number of hills per square meter, and hill-to-hill distance, along with overall crop density, was assessed using established procedures. Additionally, the soil composition was identified as clay in both cases.

2.2. Selected Combine Harvester

The BRRI whole feed combine harvester, specifically the BRRI WCH2021 model, was chosen and deployed for the paddy harvesting operation at the experimental site. This harvester is produced by the Bangladesh Rice Research Institute (BRRI), an institution working under the Ministry of Agriculture, Government of Bangladesh, as part of the SFMRA project to develop domestically appropriate whole-feed combine harvesters. The efficiency and performance of the harvester were evaluated through the actual cutting of paddy in the field. For a visual representation, refer to **Figure 2**, and for detailed technical specifications, consult **Table 1**.

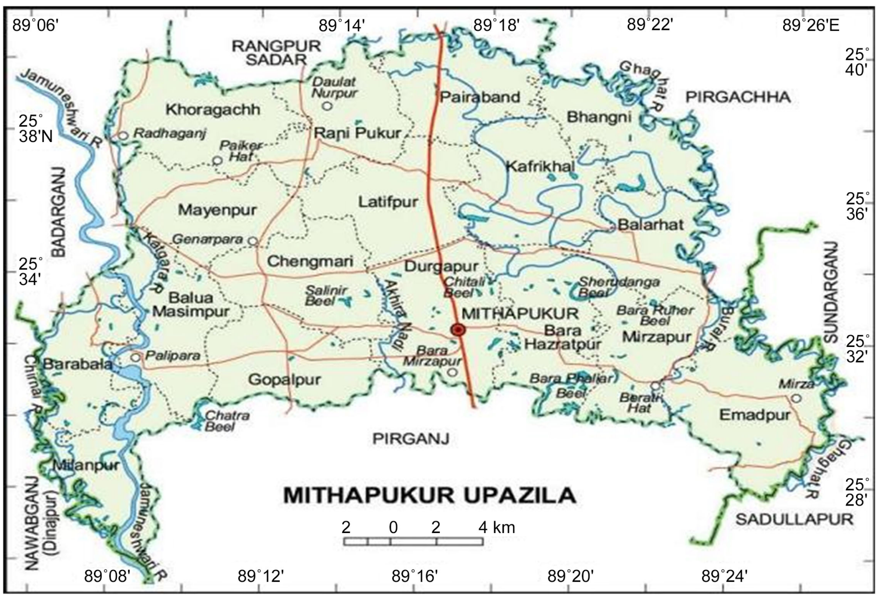

Figure 1. Experimental field trial site.

Figure 2. Operating of paddy harvesting.

Table 1. The specification of the BRRI Whole Feed Combined Harvester.

Particulars	Unit
Model	BRRI WCH2021
Dimension, mm (L*W*H)	5200 × 1800 × 2600
Threshing drum (L, Φ)	2000 mm, Φ620
Cutting width, mm	1500
Engine power, hp	87
Rubber track (Crawler)	400 × 90 × 51
Fuel tank, L	60
Grain tank, kg	600
Power transmission	Mechanical + HST
Total weight, kg	3000
Ground clearance, mm	300
Traction load, $kN \cdot m^{-2}$	20.7
Traction Area, m^2	1.376 for two crawlers
Harvesting capacity, ha	0.7 - 1.0
Forward speed, $km \cdot h^{-1}$	3 - 4
Fuel consumption, $L \cdot h^{-1}$	3.5 - 4
Total harvesting loss, %	Less than 1%

2.3. Paddy Harvesting Using BRRI Combine Harvester

Three plots were carefully chosen to assess the operational parameters of the harvester, including operational speed, field capacity (measured in hectares per hour), fuel consumption, and grain losses attributed to the combine harvester. The plot sizes were determined using a measuring tape. Additionally, three smaller areas, each measuring 1 meter by 1 meter, were randomly selected within the plot to evaluate shattering loss. Following harvesting, three 1-meter by 1-meter plots were randomly designated, and any scattered spikes within those areas were collected. It is worth noting that all tasks related to paddy harvesting, from the actual harvesting to the subsequent cleaning processes, were seamlessly executed in a single pass of the combine, as depicted in **Figure 2**.

2.4. Performance Indicating Parameters

Various indicators were pinpointed to assess the technical performance of the BRRI comprehensively combine harvesters during the paddy harvesting process. These indicators encompassed the following key aspects: 1) operational time, 2) labor needed for harvesting, 3) fuel consumption, 4) field capacity, 5) working speed, 6) effective harvesting time, 7) grain yield, and 8) grain losses. Each of these metrics played a crucial role in evaluating the overall efficiency and effectiveness of the combine harvester in the context of paddy harvesting operations.

2.5. Field Capacity

Several key parameters were considered during the paddy harvesting operation to assess the field capacity. These included measuring the plot's area, the machine's forward speed, the cutting width, and the time to harvest the designated area. These metrics provided valuable insights into the harvester's efficiency and productivity in the context of paddy harvesting.

2.6. Forward Speed

The forward speed was quantified by dividing the distance covered by the time the machine took to traverse that distance. This procedure was replicated six times within each plot to ascertain the average forward speed. The calculation for determining the forward speed of the combine harvester was based on the equation proposed by Hunt [18]. This method provided a reliable means of evaluating the harvester's operational efficiency in the field.

Forward speed,

$$S = 3.6\frac{D}{t} \tag{1}$$

where,

S = Forward speed (km/h)

D = Distance (m), and

t = Time (sec).

2.7. Field Performance Parameters

The criteria for evaluating field performance encompass parameters such as machine running speed, theoretical field capability, actual field capacity, field efficiency, work per hour, and fuel consumption. Field efficiency, a significant metric, is the ratio between effective and theoretical field capacity [19]. Theoretically and effectively, field capacity is calculated using the formulas outlined below. These metrics provide a comprehensive understanding of the machine's performance and productivity in the field.

Theoretical field capacity (ha/h),

$$FC_{Theo} = \frac{A}{E} \tag{2}$$

where,

E = Effective operation time (h) and

A = Area of land reaping at the specified time (ha).

2.8. Effective Field Capacity

The effective field capacity quantifies the average rate at which the harvester covers the field, considering the total time spent on the operation. It is calculated by dividing the area covered by the total time taken. Determining effective field capacity involves meticulous measurement and consideration of all time-related elements throughout the harvesting process, as outlined by Hunt [18]. This metric provides a practical assessment of the harvester's real-world performance in the field.

Effective field capacity (ha/h),

$$FC_{Eff} = \frac{A}{T} \tag{3}$$

where,

T = total time for reaping operation (h) and

A = area of land reaping at the specified time.

$$\text{Field efficiency}(\%) = \frac{\text{Effective field capacity}}{\text{Theoretical field capacity}} \times 100 \tag{4}$$

2.9. Fuel Consumption

Fuel consumption was determined after harvesting. Before starting the harvesting operation, the fuel tank of the combine harvester was filled up. At the end of the harvesting operation, the required fuel to fill the tank was determined by using a measuring flask. The following equation determined fuel consumption per unit area [18].

Fuel consumption (l/ha),

$$F = \frac{Fa}{A} \tag{5}$$

where, Fa = Fuel used during operation (l) and

A = Area of operation (ha).

2.10. Determination of Mechanical Harvesting Losses

Four distinct types of losses were considered in the context of using a combine harvester. These include 1) shatter loss, 2) cutter bar loss, 3) cylinder loss, and 4) separating loss. In the experimental setup, specific procedures were employed to measure these mechanical harvesting losses meticulously. This systematic approach ensured a comprehensive evaluation of the efficiency and effectiveness of the combine harvester in minimizing these various losses during the harvesting process.

2.10.1. Shatter Loss

Shatter losses in direct combination pertain to the heads, pods, or ears, as well as free grain, that are lost during the cutting and conveying operations. The quantification of shattering loss was carried out using the equation proposed by Hunt [18]. This formula provided a reliable method for evaluating the extent of shatter losses incurred during direct combining, offering valuable insights into the efficiency of the harvesting operation.

$$\text{Shatter loss}\left(\text{kg/ha}\right) = \frac{D}{A} \tag{6}$$

where,

D = Average grain dropped on the ground during cutting and conveying (kg) and

A = Area Covered (ha).

2.10.2. Cutter Bar Loss

Cutter bar loss refers to the grains lost because of rough handling by the cutter bar during harvesting. The calculation for determining cutter bar loss was based on the equation put forth by Hunt [18]. This formula serves as a valuable tool for quantifying the extent of grain loss attributable to the operation of the cutter bar, providing crucial insights into the overall efficiency of the harvesting process.

$$\text{Cutter bar loss}\left(\text{kg/ha}\right) = \frac{G}{A} \tag{7}$$

where,

G = Average weight of grain lost due to rough handling of the cutter bar (kg)

A = Area Covered (ha).

2.10.3. Cylinder Loss

Cylinder loss in the context of combine harvesting refers to grains lost out of the rear of the combine in threshed heads. The calculation for determining cylinder loss was established by Hunt [18] through a specific equation. This formula provides a reliable means of quantifying the extent of grain loss attributed to the operation of the cylinder, offering valuable insights into the overall efficiency of the harvesting process.

$$\text{Cylinder loss}\left(\text{kg/ha}\right) = \frac{H}{A} \tag{8}$$

where,

H = Average weight of un-threshed heads lost out the rear of the combine (kg)

A = Area Covered (ha).

2.10.4. Separating Loss

Separating loss in the context of combine harvesting refers to the grains lost out of the rear of the combine in threshed grain. The determination of separating loss involved the utilization of equations outlined by Hunt [18]. These specific formulas provide a structured approach for quantifying the extent of grain loss attributed to the separating process, offering valuable insights into the overall efficiency of the harvesting operation.

$$\text{Separating loss}\left(\text{kg/ha}\right)=\frac{K}{A} \tag{9}$$

where,

K = Average weight of threshed heads lost out the rear of the combine (kg)

A = Area Covered (ha).

2.10.5. Total Loss

The total manual harvesting loss was calculated by aggregating all individual losses incurred. Specific equations were applied to determine the total manual harvesting loss and express it as a percentage of the total yield to arrive at this loss. This is a clear and concise statement of the process used to calculate the rate of manual harvesting loss. The sentence describes a systematic approach to evaluating overall losses during manual harvesting. This approach is comprehensive, meaning that it considers all relevant factors. The data collected from this evaluation can then be used to analyze and optimize the harvesting process.

Total loss,

$$\begin{aligned}L\left(\text{g}\right)=\ &\text{Shutterloss}\left(\text{g}\right)+\text{Cuttingloss}\left(\text{g}\right)+\text{Gatheringloss}\left(\text{g}\right)\\&+\text{Carryingloss}\left(\text{g}\right)+\text{Threshingloss}\left(\text{g}\right)+\text{Cleaningloss}\left(\text{g}\right)\end{aligned} \tag{10}$$

$$\text{Loss}\left(\%\right)=\frac{Y}{L}\times 100 \tag{11}$$

where,

Y = Total yield (g)

L = Total loss (g).

3. Results and Discussion

3.1. Harvesting Capacity of Combine Harvester and Land Size

The harvesting area's size and configuration significantly impact the harvester's performance. In the case of BRRI combine harvesters, their field capacity is closely tied to the dimensions and layout of the land being harvested. Research results indicate that the harvester's capacity increases as the size of the harvesting plot expands, mainly due to a reduction in the frequency of turning events. Elsoragaby, Yahya [20] have pointed out that the performance of combined harvesters is notably affected by a reduction in the size and alteration in the shape of the plot area. This observation aligns with the findings of Islam, Alam [21], which suggest that irregularly shaped plots can significantly decrease the field performance of the combine harvester. Therefore, selecting the crop field based on the land's size is essential to optimize the field performance of the combined harvester.

3.2. The Field Capacity of Combine Harvester Concerning Plot Length

The field capacity of the BRRI combine harvester showed variation in the plot length, a phenomenon primarily influenced by the frequency of turning events. As the plot length increased, so did the field capacity of the combine harvester. Notably, the lowest field capacity was observed in plots with a length of 25.6 meters. These findings underscore the importance of having a plot length exceeding 38.6 meters for optimal operation of the BRRI combine harvester, particularly when equipped with a 1.5-meter cutting width, as it allows for reduced turning events and enhances overall efficiency during the harvesting process (**Table 2**).

3.3. Turning Events

To optimize efficiency and minimize turning events, it is recommended that the BRRI Combine harvester be operated in plots with a length exceeding 38.6 meters. Currently, rice fields are often fragmented due to shifts in ownership, and farmers may deliberately divide the land to facilitate better water management in rice cultivation. The effectiveness of harvesting operations is closely tied to plot size and length. Operators strategically maneuvered the farm machinery lengthwise to further mitigate the need for frequent turns, enhancing overall harvesting efficiency. This approach proves beneficial in managing fragmented rice fields and ensuring a smoother harvesting process.

3.4. Time Loss in Turning

The time lost during turning maneuvers decreases proportionally with increased plot size. In smaller plots, a higher frequency of turns is required, leading to more significant time loss. To operate the BRRI combine harvester at full capacity and minimize turning-related inefficiencies, selecting plot areas exceeding 1200 square meters is advisable, particularly when equipped with a 1.5-meter cutting width. Similarly, for the efficient operation of the BRRI whole-feed combine harvester, a plot size of over 800 square meters is recommended. These considerations are pivotal in ensuring optimal performance and productivity during harvesting.

Table 2. The technical performance of combined harvester.

Plot	Forward speed, (km/h)	Fuel Consumption, (l/ha)	Fuel Consumption, (l/h)	Effective Field Capacity, (ha/h)
1	3.00	7.50	3.5	0.00366
2	3.50	7.00	3.5	0.00263
3	4.00	7.00	3.25	0.00270
Average	3.5	7.17	3.41	0.0030

3.5. Field Efficiency

The field productivity of the BRRI combine harvester is closely linked to the size of the land it operates on. The performance of the combine harvester demonstrated variation based on the size of the land. Specifically, field efficiency showed an upward trend with increased land size. The highest levels of field efficiency were observed in plots exceeding 1200 m^2. Conversely, plots with an area of 800 m^2 noted the lowest field efficiency. These findings highlight the significant impact that land size has on the operational efficiency of the BRRI combine harvester, emphasizing the importance of selecting appropriately sized plots for optimal performance.

3.6. Field Performance of BRRI Combine Harvesters

The findings indicate that the operational speed of the combine harvester ranged from 3.36 to 4.50 km/h during the harvesting process. According to ASAE Standards (2009), large and medium-sized combine harvesters typically operate within a range of 3 to 6.5 km/h during harvesting. In the case of the mini combine harvester, the theoretical and actual field capacity were measured at 0.19 and 0.11 ha/h, respectively (**Table 3**). Conversely, for full-feed and head-feed combine harvesters, the theoretical and effective field capacities were determined to be 0.50 and 0.36 ha/h, respectively, as noted by Alizadeh and Allameh [8]. Muazu, Yahya [22] further emphasized that the lowest field capacity (0.67 ha/h) was associated with the highest loss time (1.54 h) during the paddy harvesting operation, resulting in a relatively lower actual field capacity (**Table 4** and **Table 5**). Grain loss during harvesting and the efficiency of the harvester are shown in **Figure 3** and **Figure 4** respectively. While the harvesting capacity of the BRRI combine harvester may be considered relatively low, it stands out for its adaptability to both smaller and larger fields, which is a notable advantage.

3.6.1. Time Distribution of Combined Harvester Operation

During the harvesting operation, the time allocation for the BRRI combine harvester was distributed as follows: 58% was spent in actual harvesting, 23% in turning maneuvers, and the remaining 19% encompassed activities like repairs, idle time, and work stoppage due to rain. Elsoragaby, Yahya [20] noted that in the case of large, estimated combine harvesters, 60.0% of the total time was dedicated to actual rice harvesting, with the remaining 40% being allocated to turning manoeuvring. Unloading activities (**Figure 5**). In contrast, medium-sized combine harvesters devoted 71.7% of their time to harvesting and the remaining 28.3% to turning, maneuvering, and unloading. Muazu, Yahya [22] reported that for conventional combine harvesters, 66% of the total time was spent in actual harvesting, while the remaining 13% was used for turning and manoeuvring activities. Turning, reversing, and unloading are essential but time-consuming activities; the aim is to minimize the time lost, as it can account for as much as 40% of the operation's duration [23]. This unavoidable time loss can be mitigated with strategic planning and innovative practices.

Table 3. Grain losses during harvesting by a BRRI combine harvester.

Plot	Total loss, % (Boro/2022)	Average loss, % (Boro/2022)	Total loss, % (Aman/2022)	Average loss, % (Aman/2022)
Plot-1	0.6		0.53	
Plot-2	0.48	0.56%	0.44	0.48%
Plot-3	0.57		0.48	

Table 4. Field capacity and efficiency of combined harvester.

Parameters	Plot-1	Plot-2	Plot-3	Plot-1	Plot-2	Plot-3
	Boro/2022			Aman/2022		
Travel speed (km/h)	3.25	3.5	4.0	3.25	3.5	4.0
Working width (m)	1.5	1.5	1.5	1.5	1.5	1.5
Total work time (min)	22.35	15.32	26.07	29.08	20.41	25.2
Delivery time (min)	1.52	1.39	2.36	2.46	1.45	2.13
Operation time (min)	21.23	14.33	24.12	27.03	19.46	23.07
Turning Time (min)	9.23	5.47	8.15	9.45	6.46	8.19
EFC (ha/h)	0.12	0.10	0.07	0.08	0.11	0.09
TFC (ha/h)	0.23	0.16	0.18	0.21	0.19	0.21
FE (%)	52.17	62.5	38.9	38.2	57.9	42.85

Table 5. Crop and field parameters of different paddy varieties.

Particulars	Plot-1	Plot-2	Plot-3	Plot-1	Plot-2	Plot-3
Variety	Hybrid dhan	Hybrid dhan	BRRI dhan74	BRRI dhan34	BRRI dhan93	BRRI dhan95
Soil moisture content, %	16	15.5	16.5	17	16.5	18.5
Grain moisture content (w. b), %	22.3	25.5	23.4	19.4	20.7	23.6
Straw moisture content (w. b), %	24	21.5	25.7	20.3	23.1	24.2
Plant height, cm	115.6	115.2	106.8	135.3	112.3	128.5
Length of panicle, cm	107	108.4	92.3	121.7	101.5	117.2
No. of tillers per panicle, no	11.5	12.3	15.7	15.4	10.8	13.2
The number of hills/m^2, no.	14	13	14	17	14	12
No. of plants per hill	12	13	13	15	13	10
Straw grain ratio	1.24	1.27	1.45	1.40	1.56	1.61

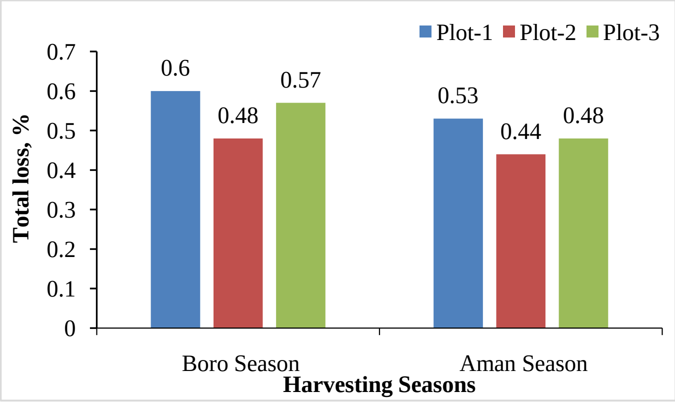

Figure 3. Grain losses during harvesting seasons.

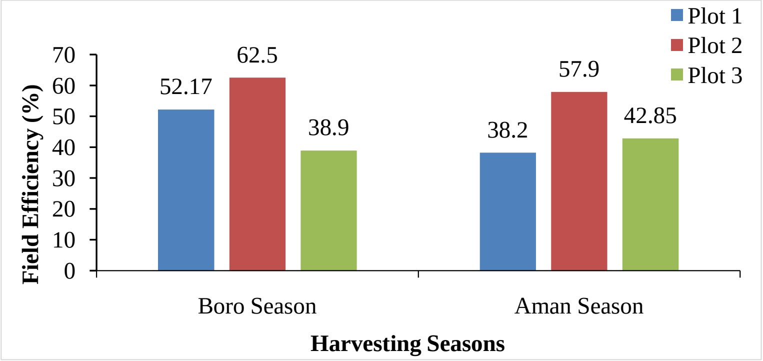

Figure 4. Field Efficiency (%) of BRRI combined harvester regarding seasons.

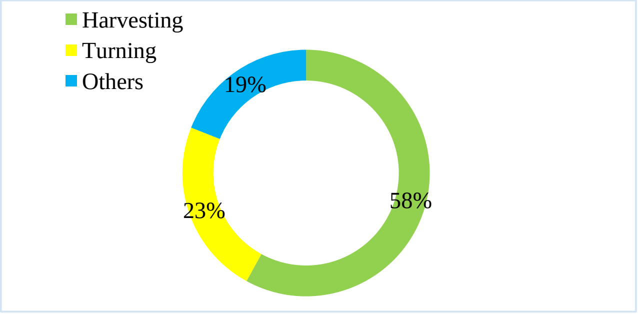

Figure 5. Time distribution of BRRI WCH operation during harvesting of paddy.

3.6.2. Repair and Maintenance

Repairs and maintenance constitute crucial aspects in evaluating a BRRI combine harvester. During the harvesting operation, the harvester necessitated certain repair and maintenance tasks, including reel assembly, addressing clogs in the threshing component caused by moisture and densely packed crop, managing crop lodging, ensuring hydraulic functionality for cutter bar movement, and mitigating high noise and vibration levels stemming from using a single-cylinder engine. These activities are integral in ensuring the optimal performance and longevity of the harvester, highlighting the importance of regular maintenance practices.

3.6.3. Machine Status during Operation

The mechanical malfunctions encountered by the combine harvester during the harvesting operation have been compiled and are presented in Table 6. This summary provides a comprehensive overview of the specific issues faced, aiding in the assessment and potential resolution of these mechanical challenges.

3.6.4. Operators' Thoughts

Operators were invited to provide their feedback on specific issues, and their comments have been compiled and condensed for easy reference in Table 7. This summary is a valuable resource for gaining insights directly from those on the ground, which can inform future decisions and improvements related to the discussed matters. Their input is crucial in ensuring the continued efficiency and effectiveness of operations.

Table 6. Machine status during operation.

Parameters	Comments
Header unit	Reel successfully gathered the standing and leaning crops.
Cutting unit	The cutter bar moves smoothly and successfully cuts the crop. Any uncut plant was not found.
Conveying unit	Cut crop conveyed to the threshing drum by conveyer belt. Overfeeding clogged the conveying unit.
Threshing unit	Grains were separated from the panicle successfully.
Cleaning unit	A cyclone separator cleaned grains. The cleaning was so good.
Gear Changing	The gear-changing mechanism is straightforward.
Power transmission system	The gear mechanism is easy for the operators.
Vibration and noise	The vibration characteristics of various structures are notably pronounced, particularly at the header component of the harvester, where factors such as load and road surface conditions contribute to its robust vibration. This heightened vibration, and accompanying noise from the cutting components adversely affect the operator's comfort and the overall lifespan of the equipment frames. Additionally, the continuous vibration led to the loosening of nuts and bolts. The machine's vibrations significantly impacted the operator's comfort. During the grain delivery, the lifting cylinder exhibited noticeable vibrations while unloading grains. These findings underscore the importance of addressing and mitigating vibration-related issues for enhanced operational efficiency and operator comfort.
Turning	It is easy to turn the harvester, especially right turning.
Harvesting speed	The machine operates at a slightly reduced speed, and attempts to increase this speed result in clogging issues in the conveyor belt's feeding mechanism. Conversely, running the machine at excessively high speeds leads to pronounced vibration at the front header, which impacts the reel's movement. This heightened vibration and reel instability ultimately increase paddy loss at the header. Striking the right balance in operational speed is crucial for maintaining smooth and efficient harvesting processes.

3.7. Farmers' Statements

Farmers were invited to provide feedback and comments on various pertinent issues. These comments have been compiled and are presented in a summarized form in Table 8. This compilation serves as a valuable resource for gaining insights and perspectives directly from the end-users, which can inform future decisions and improvements in the context of the discussed matters.

3.8. Overall Observations

Observations about the overall condition of the crop and the land have been meticulously recorded and are succinctly summarized in Table 9. This compilation serves as a valuable reference for assessing the health and status of the crop and the land, providing essential data for further analysis and decision-making in agricultural practices.

Table 7. Operators' observations during the operation of the combine harvester.

Parameters	Observations
Operation	Operators feel comfortable operating the harvester. Seating arrangement helped the operator ease of operation.
Unusual breakdown	An unusual breakdown was not observed during the operation.
Straight movement	No problem faced in a straight movement
Lowering and uplifting in the field	No problem was found in uplifting on lower and higher ground.
Driving on the road	There is no difficulty in moving on the road. However, turning in the road caused crawler damage.
Trouble	It is an almost trouble-free machine. Before operating in the field, precautions should be taken for proper repair and maintenance.

Table 8. Farmers' comments on the performance of combine harvester.

Parameters	Comments
Grain cleaning	More than 97% of cleaned grain was obtained. Every farmer is satisfied with the grain cleaning.
Grain damage	Farmers did not find any significant amount of grain damage.
Status of straw after harvesting	Straws were chopped after harvesting. After getting it from a combine harvester, every farmer thought they could keep straw for a long time.
Grain collection	Grains are collected very easily. Farmers showed satisfaction with grain collection through the bag.
Threshing loss	Farmers find nominal un-threshed grain in the straw, which is acceptable to the farmers.
Harvesting capacity	Harvesting capacity is very high. Farmers showed satisfaction with the harvesting capacity of the BRRI combine harvester.

Table 9. Overall observations on the crop and land condition of a harvested field.

Parameters	Comments
Land condition	Sandy loam soil. The land is good. 86 - 125 mm standing water was found in the field
Depth of mud, mm	20 - 35
Crop position	Standing. The lodged crop was observed in some places in the fields.
Inclination of crop	The percentage of inclined crops is about 60% with an angle of 70 degrees.
Crop density	Moderate to high-density
Crop height, mm	1200 - 1650
Straw left in the field after harvesting, mm	100 - 130
Overall comments	Farmers showed satisfaction with the performance of the BRRI combine harvester.

4. Conclusion

The assessment of the BRRI combine harvester has concluded with highly positive outcomes, underscoring its notable effectiveness and user satisfaction. Its versatility in accommodating various small and large field sizes highlights its broad applicability. For optimal performance with a 1.5 m cutting width, operating on plots exceeding 1500 m^2 is advised. The harvester exhibits a theoretical field capacity of 0.23 ha/h, complemented by an actual capacity of 0.11 ha/h. The most favourable grain loss rate (1.64%) was achieved under specific conditions, featuring a moisture content of 23.2% and a forward speed of 3.5 kg/h. This technology represents an invaluable opportunity for farmers of all scales nationwide, enabling them to mechanize rice harvesting and embrace advanced agricultural practices. In the context of Bangladesh's fragmented land, this locally developed harvester holds a distinct advantage over its imported counterparts in terms of efficiency. With augmented governmental policy support and financial backing, the BRRI combine harvester could substantially decrease reliance on imported agricultural machinery and pave the way for export opportunities. The collaborative endeavours between local agricultural machinery manufacturers and BRRI scientists, culminating in developing this machine, demonstrate Bangladesh's immense potential for success. This achievement can revolutionize the agricultural mechanization landscape in the country, marking a significant milestone in its agricultural sector. The introduction of BRRI's whole feed combine harvester heralds a transformative era for Bangladesh's agriculture.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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