Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 12 Issue 05, May-2023

Design and Development of BRRI Solar Power Operated Paddy Winnower

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ABSTRACT - The solar power operated paddy winnower was developed and performance was evaluated out at three feed rates 189.99 kg/h, 196.94 kg/h, and 203.94 kg/h for (Bangladesh Rice Research Institute) BRRI dhan29 and 195.99 kg/h, 196.56kg/h and 200.42kg/h for BRRI dhan28 respectively. The paddy winnower was mounted with a 0.25 hp DC motor and connected to a 360-watt photovoltaic solar panel. The highest cleaning efficiency of about 94.6 % was achieved for a feed rate of 209.30kg/h at the main outlet. The highest output capacity of 203.94kg/h was achieved at a feed rate of 225 kg/h. It was observed that the cleaning efficiency for both the paddy varieties decreased by increasing the feed rate.

KEYWORDS: Solar, paddy, winnower, cleaning, output capacity, performance

INTRODUCTION

Bangladesh is called an agricultural country and its contributed 11.63 percent of the country's GDP in 2021[23]. Bangladesh's economy is primarily based on agriculture[26]. Paddy is the most important grain of all food grains[21]. Three-fourths of the world's population consumes it[7]. Rice "is the main meal for over half of the world's population," according to Dr. Jacques Diouf, Director-General of the UN Food and Agriculture Organization (FAO) [8].

In Bangladesh, rice is the primary food consumed by 135 million people. It provides over 48% of rural employment, about two-thirds of the nation's total calorie supply, and roughly 50% of the average person's protein intake. In Bangladesh, the rice industry generates one-sixth of the country's income and one-half of the agricultural GDP. In 1971, when Bangladesh's population was only about 70.88 million, the nation produced a total of about 10.59 million tons of rice. To feed its 135 million citizens, the nation is now producing roughly 25.0 million tons[5]. In Bangladesh, rice is grown on around 75% of the country's cropland and on more than 80% of its irrigated land[16]. Bangladesh ranks fourth among the world's top-producing nations of milled rice in 2020–2021 (34.6 million metric tons) [27].

Rice is crucial to Southeast Asia's effort to eradicate hunger and malnutrition. Because it accounts for 50% of the region's population's calorie consumption, rice is the single most significant food source. Nearly 30% of the world's rice yield, or 48 million ha, is grown in this region. In 2018, 220 million tons of rice were produced[28]. Southeast Asia has the highest rice consumption, with Bangladesh remaining at the top of the per capita rice consumption chart at 268.9 kg[25].

Harvesting, threshing, drying, winnowing, and packaging are the main unit operation for paddy processing[17]. By using air pressure, the process of winnowing removes foreign matter, or chaff, from the paddy[19]. Winnowing involves removing the grains from straw or chaff. Numerous farmers manually grind paddy crops or tramp them under animals' feet, making cleanup more challenging [6]. In many parts of India, paddy threshing is still done either with animal treading or manually by beating on wooden planks or stones, according to research [2]. Traditional cleaning techniques including natural airflow and tiny fans are employed. This technique produces just 40–45 kg/hr, which is a very low output, and it takes a long time [6]. The manual operation of the belt conveyor resulted in inconsistent feed materials into the cleaning unit, necessitating the development and usage of an automatic winnowing system[3]. The energy usage of a power-operated paddy winnower is substantial. In light of this, a project to create a solar-powered paddy winnower was started. This device can be utilized in places where electricity is either unavailable or prohibitively expensive[6].

In comparison to a winnower that is operated manually, the machine has a very high capacity. At

Tamil Nadu Agricultural University (TNAU) Coimbatore, motorized paddy winnowing equipment was created [24]. Energy-operated paddy winnower has a feed hopper for holding the grain while it is being cleaned. Grain is discharged over a scalper, and larger size impurities are removed [29].

Solar power-operated paddy winnowing system is much more congenial and relevant to the contemporary upcoming days of globalization and digitalization [22]. Due to the constant blower speed, power-operated winnowers have been very successful at isolating grains from undesired particles or foreign materials. However, the blower motor requires electric power to work. Wire-connected energy and the availability of other non-renewable electricity generation are frequently insufficient, inconsistent, and unaffordable in several rural areas of many third-world countries [30]. Compared to traditional electric energy, solar energy is considerably more affordable and requires less attention[12]. The government of Bangladesh has prepared a strategic plan to make use of the plentiful solar energy in various ways, with an ambition to build 600 MW of capacity by the end of 2021. By installing 6.9 million solar household systems up to 2018, a total capacity of 220 MW of solar energy might be generated by Solar Home Systems (SHSs) [13].

By the year 2030, the government of Bangladesh intends to generate 4190 MW of power from these renewable resources[14]. Bangladesh has a significant potential for using solar radiation to produce power because of its geographic location. The nation can generate 1018 × 1018 J of energy from the solar radiation it absorbs on average, which ranges from 4.0 to 6.5 kWh/m^2 per day[4] [14]. Several research teams from various colleges and research institutions are attempting to advance the current renewable technologies under the Infrastructure Development Company Limited (IDCOL) finance plan[13].

Nevertheless, it's necessary to design and develop an effective solar power-powered paddy winnower for farmers who may use it to harvest high-quality, clean paddy while saving time, labor, and grid electricity [9]. This study aims to design and develop high-capacity solar power paddy winnower and to evaluate the performance of solar power paddy winnower.

Materials and Methods

The study was conducted at Bangladesh Rice Research Institute, Gazipur, Dhaka, Bangladesh. Two paddy varieties namely BRRI dhan28 and BRRI dhan29 were used in evaluating the solar-powered winnower. 50 kg of sample was used for each experiment and it was replicated thrice[20].

Considerations for Design

The equipment should finish its fundamental job of cleaning the grain. It should be cost-effective. The procedure shouldn't need to be repeated. To make transportation easier, the device should be portable. To lessen farmer fatigue, the design should be improved. The attachments ought to make use of inexpensive components, techniques, and locally accessible common parts[10].

Feed rate

For the BRRI Dhan28 type paddy variety, the performance was conducted at three feed rates of 209.3kg/h, 211.76kg/h, and 216.86kg/hand, and for the BRRI Dhan29 type paddy variety, it was done at 202.24kg/h, 211.76kg/h, and 225kg/h, correspondingly[20].

Measurement of motor rpm and air flow rate

On a digital screen, the rotations per minute were represented using a digital tachometer (DT2234C+). The airflow rate of the Blower was assessed during the experiment using a digital anemometer (MS6252A) [20].

Winnowing procedure:

The bag containing the 50 kg of paddy was placed into the hopper after the winnower was checked. When the winnowing process was fully completed, the stopwatch was paused. Using an anemometer, the airspeed rate was measured. After the winnowing process was complete, the weight of sound and healthy paddy was measured, while the weight of chaff, immature paddy, and dust was also measured separately using a weight machine.

Performance assessment of solar power operated paddy winnower

To gather accurate information about the machine, such as grain ratio, Percentage of blown grain, cleaning efficiency, and adjustability to numerous types of crops in contrast with conventional techniques, performance measurement was of utmost significance and was carried out under controlled settings. The winnower's output capacity and feed rates on cleaning efficiency were also calculated[20].

Determination of grain ratio

Impurities, cleaned grain, and a paddy sample's weight were all measured. It was determined the grain ratio [18].

$$GR = \frac{W1}{W2} \qquad (1)$$

Where,

GR= Grain Ratio, W_1=Grains weight in sample, W_2= Total sample weight

Percentage of blown grain

The sound grain carried away along with the straw and chaff was calculated [18].

$$\text{Percentage of blown grain} = \frac{F}{A} \qquad (2)$$

Where, F= Quantity of whole grain collected at chaff outlet per unit time, kg and A= Total grain input per unit time by weight, kg.

Cleaning efficiency

The cleaning efficiency of the winnower can be defined as the ability to separate the sound grains from a mixture of dust, straw, and chaff [18].

$$\text{Cleaning efficiency } (\eta) = \frac{P}{Q} \qquad (3)$$

Where, P =Weight of whole grain per unit time at main grain outlet, kg and Q= Weight of whole material per unit time at the main outlet, kg.

Design Considerations

Optimal fan wind speed and corresponding required rpm

The ideal wind speed for cleaning paddy fields is 900-1400 ft/min, or 4.57-7.11 m/s. The centrifugal fan's shaft would need to rotate at a certain rate (rpm) to generate this wind speed. The fan affinity law was used in the calculation [11].

$\frac{n1}{Q1} = \frac{n2}{Q2}$-- (4)

Where, Q_1 = first air flow rate (m^3 /min), n_1 = rotational speed corresponding to Q_1 (rpm), Q_2 = second air flow rate (m^3/min) and n_2 = rotational speed corresponding to Q_2 (rpm).

$Q_1 = Av$-- (5)

Where, A=Cross sectional area and v = velocity of wind.

Due to the equal diameter of two pulleys here, the optimal fan wind speed and corresponding required rpm werethe same.

Pulley diameter

To size, the correct dimensions of the pulley, a ratio between rpm and pulley diameter was used[11].

$n_1 d_1 = n_2 d_2$--(5)

Where, d_1 = diameter of driver pulley, cm, n_1 = rotational speed corresponding to d_1, rpm, d_2 = diameter of driven pulley, cm, and n_2 = rotational speed corresponding to d_2, rpm.

Belt length

By determining the angle of contact between each pulley, the length of the V-belts between the motor and fan shaft is computed. The following formulae were used to determine the Angle of Contact [11]. The angle of contact of

the small pulley =$\theta_d = \pi - \sin\left(\frac{D-d}{2C}\right)$---(6)

thlarge pulley = $\theta_D = \pi + \sin\left(\frac{D-d}{2C}\right)$--(7)

where, D = blower pulley's diameter (inch)= 7 inch, d=motor pulley's diameter (inch)= 7 inch, θ_D= large diameter pulleys contact angle (rad), θ_d = small diameter pulleys contact angle (rad), and C = Distance between the pulley centers = 18 inch.

$\theta_d = \pi - \sin\left(\frac{D-d}{2C}\right)$---(8)

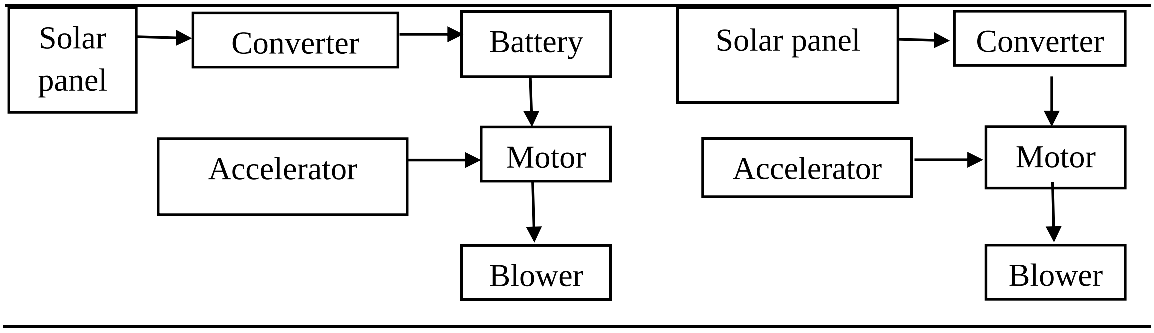
$\theta_D = \pi + \sin\left(\frac{D-d}{2C}\right)$---(9)

After determining the angle of contact between the two pulleys, the following equation was used to calculate the belt's overall outside length:

Length of belt =$\sqrt{[4c^2 - (D-d)^2]} + \frac{1}{2}(D\theta_d - d\theta_d)$-----------------------------(10)

Solar Photovoltaic Panel

To power the DC motor of the winnower, six solar panels (each 60W, 12V, 5A) were connected in parallel, on the other hand, silicon and other semiconductor materials are used to make solar cells. The charge carriers receive the energy from photons of light when they hit the cell.



a) Stored solar energy used in winnowing b) Direct sunlight used in winnowing

Fig. Flowchart of the BRRI Solar Power Operated Paddy Winnower.

Power Transmission

The blower shaft was fitted with a pulley that was the same size as the motor shaft (7 inches in diameter) and 1:1 speed reduction was accomplished by using particular pulley diameters. Finally, The drive pulley (motor pulley) and driven pulley (blower pulley) were connected by a V-belt to transfer power [20].

Winnower

Steel frame, blower, feed hopper, feed and purity adjustment mechanisms, grain outlet, immature grain outlet, DC motor, battery, chaff, and dust outlet with gear and pulley system, are the components of a winnower. The frame was made with the assumption that the paddy would fall 40 inches from the fan outlet. A blower has a horizontal shaft with two ball bearings and four curved blades fixed on it. At one end of the shaft, a small gear engages with a larger gear.

A U-belt and an electrical DC motor were employed to power the process. The motor shaft (driven pulley) drives the blower shaft (driving pulley). When the combination of paddy is exposed to the airflow, the chaff and lighter materials are blown through the chaff and husk outlet opening by the air blast, while the sound and healthy grains, which are heavier, fall simultaneously through the two-grain outlets that are connected to the winnower but are on opposing sides of the machine. The first outlet port is used to separate sound grain, while the second one is used to separate relatively less sound grain than the first. A little bit further from the sound grains outlet, immature grains that are substantially lighter will be carried by the blast and gathered by the immature grain outlet.

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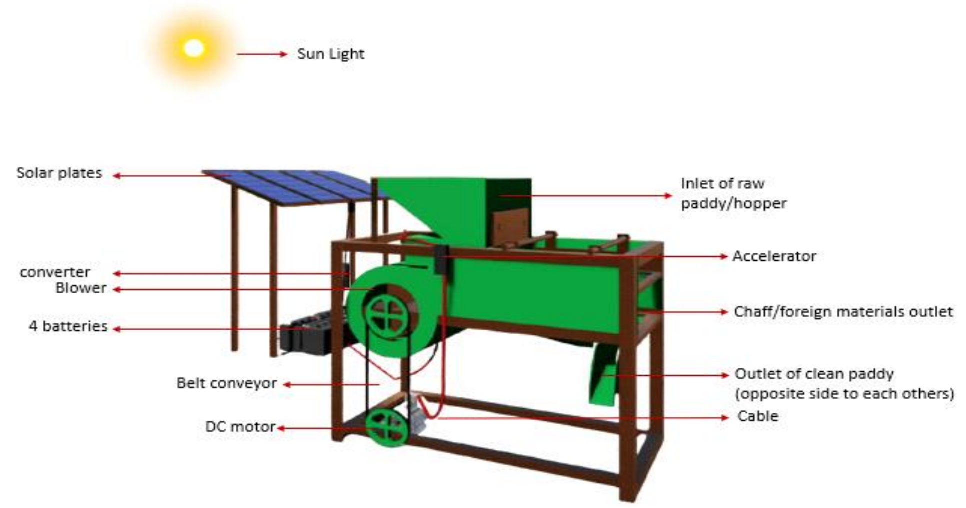
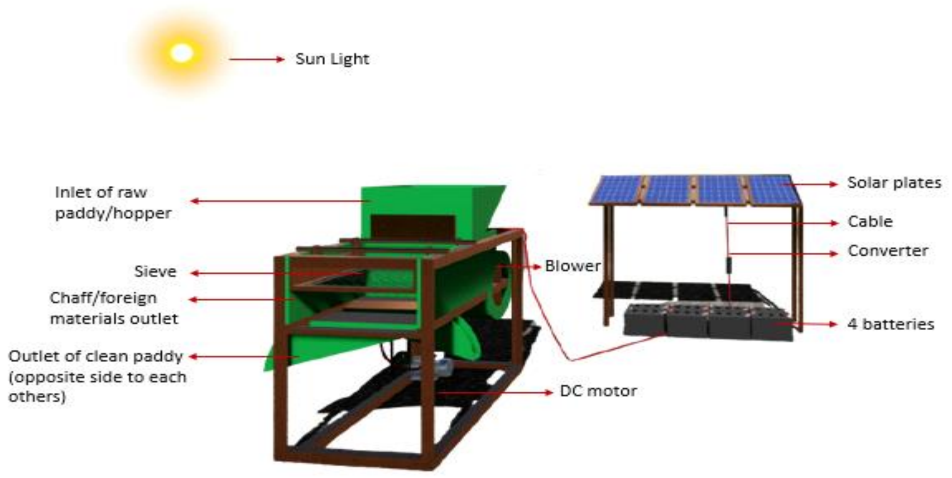
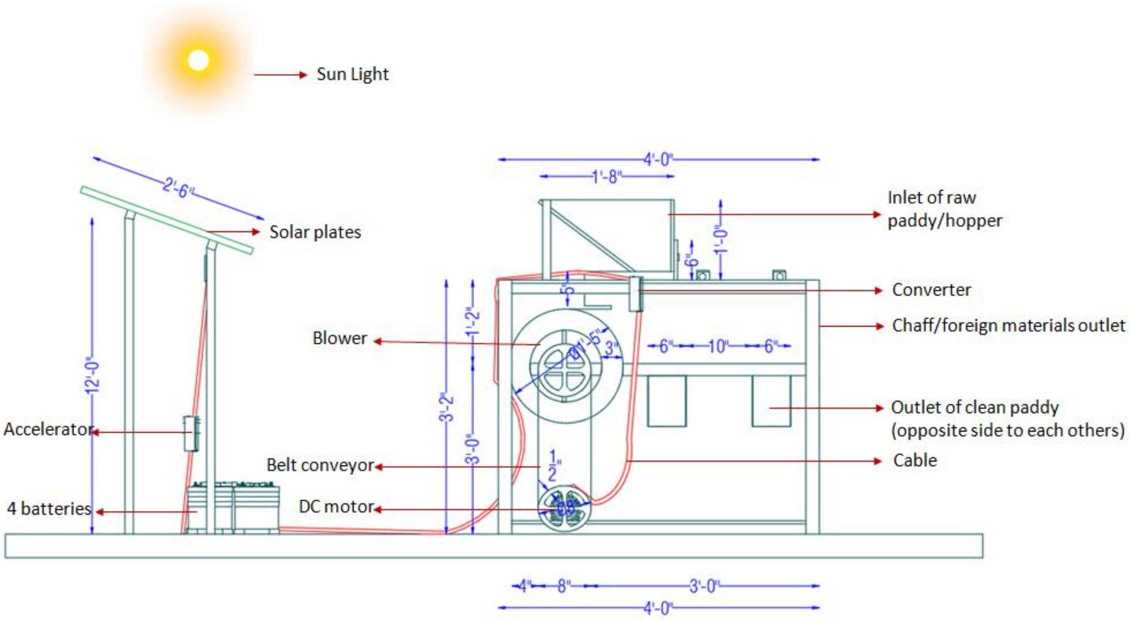


FRONT VIEW



BACK VIEW



FRONT VIEW

III. RESULTS AND DISCUSSIONS

Air flow rate

Table 1 displays the blower's air velocities at various distances from the blower shaft to the impurity exit. It displays that air velocity kept rising gradually when the anemometer was taken into the blower from the impurity exit. The highest velocity of 7.0 (m/s) was measured near to blower, the velocity of 6.5 (m/s) was the lowest at the furthest impurity exit. The mean blower speed and flow rate were found to be 450 rpm and 6.74 m/s, respectively.

Table 1: Measurement of air velocities at 5-inches below hopper outlet.

Trail	Air velocity (m/s)
1	6.5
2	6.6
3	6.7
4	6.9
5	7.0
Average Velocity (m/s)	6.74

Effectiveness of Winnower

Table 2 illustrates the effectiveness of BRRI solar power operated paddy winnower. Where cleangrain at main outlet, cleaning percentage, and grain ratio kept growing. On the other hand, the percentage of grain loss fell steadily from trail 1 to 3 and the percentage of blown grain fluctuated.

Table 2: Effectiveness of BRRI Solar Power Operated Paddy Winnower

Trail	Sample (kg)	Main outlet (clean grain), kg	Cleaning (%)	Percentage grain loss (%)	Percentage blown grain(%)	Grain ratio
1	50	44.7	89.4	1.75	0.9	0.9284
2	50	45.2	90.4	1.20	1.32	0.9288
3	50	46.8	93.6	0.78	0.89	0.9516
Average	50	45.6	91.13	1.24	1.04	0.9362

Performance evaluation

Tables 3 shows the amount of sound grain was discharged with contaminants, sound grain was received in the secondary outlet together with immature grain, and grain received in the main outlet. For BRRI dhan 29, it was observed that in case of feeding 50 kg the average amount of sound grain measured at main outlet 46.26 kg, at secondary outlet was 3.24 kg and at impurities outlet was 0.49 kg whereas the average feedrate was 213 kh/hr. On the other hand, for BRRI dhan 28, the values were 46.48 kg, 2.91 kg, 0.61 kg and 212.64 kh/hr. However, the average wind velocity was similar for both cases.

Table 3: Performance evaluation of BRRI Solar Power Operated Paddy Winnower in case of paddy variety BRRI dhan29 and BRRI dhan28.

Paddy variety	Total mass (kg)	First outlet (kg)	Secondary outlet (kg)	Impurities outlet (kg)	Feed rate (kg/h)	Wind velocity (m/s)
BRRI dhan 29	50	46.97	2.72	0.3	202.24	4.1
	50	46.5	2.96	0.54	211.76	4.2
	50	45.32	4.05	0.63	225.00	4.3
	Average	46.26	3.24	0.49	213.00	4.2
BRRI dhan 28	50	46.82	2.83	0.35	209.30	4.2
	50	46.41	2.79	0.80	211.76	4.17
	50	46.21	3.1	0.69	216.86	4.2
	Average	46.48	2.91	0.61	212.64	4.2

Effect of feed rate on cleaning efficiency

Figure 1 illustrates the effect of feed rate on cleaning efficiency for BRRI dhan29 and Figure 2 displays the effect of feed rate on cleaning efficiency for BRRI dhan28. The cleaning efficiency of BRRI dhan29 and BRRI dhan28 increased while the feed rates of both varieties kept decreasing. However, the variety BRRI dhan29 cleaning effectiveness declines more quickly than the variety BRRI dhan28 which is displayed in Figures 1 and 2. Because both types' thickness and length varied, this distinction could be seen. In comparison to variation BRRI dhan28, which was long and thin, variety BRRI dhan29 was thick and short in size. For the BRRI dhan29 type paddy variety, cleaning efficiency at the main outlet was determined to be 93.64%, 92.28%, and 91.94% for the first, second, and third feed rates, respectively. Cleaning efficiency for the BRRI dhan28 type of paddy variety at the main outlet flow was determined to be 94.6%, 93.5%, and 93.4% for the corresponding feed rates. In conclusion, BRRI dhan28 experienced the highest cleaning efficiency at 94.6%. On the other hand, BRRI dhan29 stood at its peak at 225 kg/hr. feed rate.

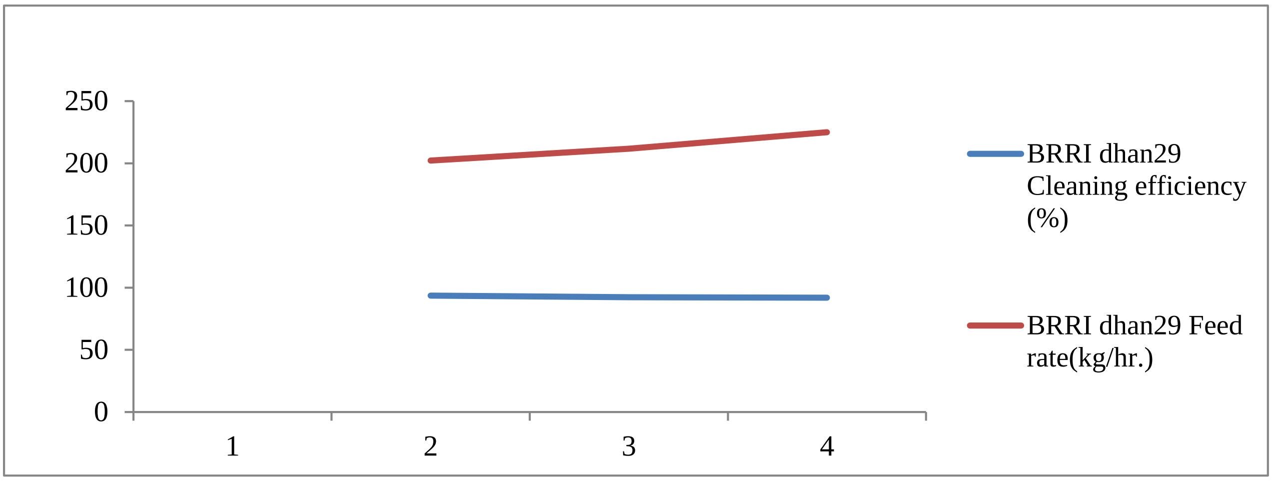


Figure 1: Effect of feed rate on cleaning efficiency for BRRI dhan29

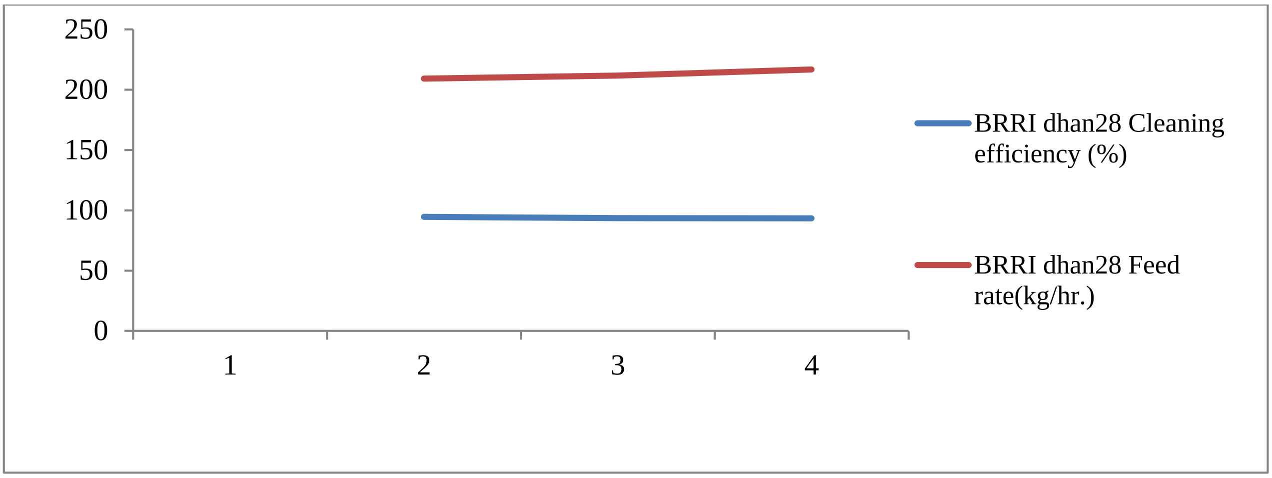


Figure 2: Effect of feed rate on cleaning efficiency for BRRI dhan28

Effect of feed rate on output capacity

Line graphs 3 and 4 illustrate the effect of feed rate on output capacity for BRRI dhan28 and BRRI dhan29. However, while the output capacity of the two varieties rose gradually,the feed rate of the two varieties also kept increasing, simultaneously. Both the BRRI dhan28 and BRRI dhan29 types' output capacity rose as the feed rate was raised, as seen in Fig. 3 and 4. In terms of output capacity, it was observed that the BRRI dhan28 type paddy variety could produce 195.99 kg/h, 196.56 kg/h, and 200.42 kg/h at the main outlet for the corresponding feed rates, whereas, the BRRI dhan29 type paddy variety, could produce 189.99 kg/h, 196.94 kg/h, and 203.94 kg/h. BRRI dhan28 type paddy variety experienced its highest feed rate and output capacity is 216.86 kg/h and 200.42 kg/h, table 3 and table 4 are shown.

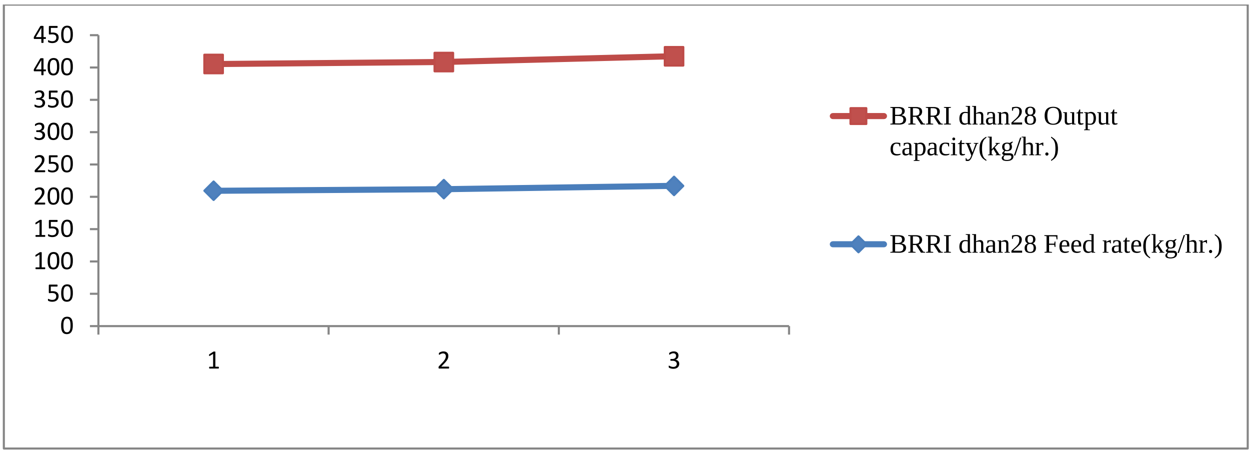


Figure 3: Effect of feed rate on output capacity for BRRI dhan28

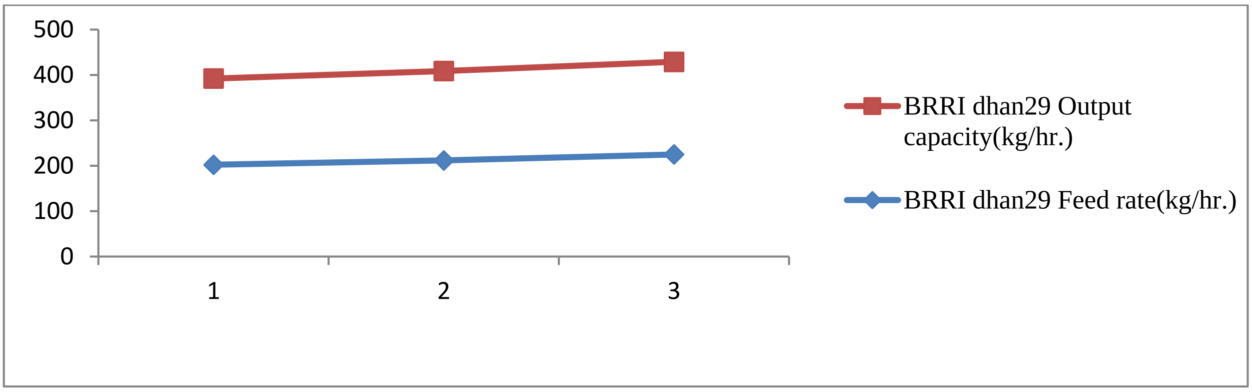


Figure 4: Effect of feed rate on output capacity for BRRI dhan29

IV. CONCLUSION

The BRRI dhan28 type of paddy variety had the highest cleaning efficiency of 94.6 percent at a feed rate of 209.30 kg/h due to its thinness, lightweight, and length, and the BRRI dhan29 type of paddy variety had the highest output capacity of 203.94 kg/h at a feed rate of 225 kg/h due to its thickness and slightly larger size than BRRI dhan28. For each of the three feed rates, the percentages of blown grain were less than 1.5%. Because of the winnower blower speed and winnowing duration, both varieties (BBRI dhan29 and BRRI dhan28) have reduced cleaning efficiency as the feed rate is increased. Due to the winnowers' blower velocity and speed, the output capacity for both varieties—BRRI dhan29 and BRRI dhan28—increases as the feed rate is increased. We should encourage farmers and agricultural machinery innovation businesses to employ solar power-run paddy winnowers while keeping an eye on the future and considering contemporary global reality. However, some limitations of these machines for winnowing operation are indicated as pointed out below: It's dependent on the weather, if the weather becomes cloudy then it will be a reason for tension. There is no solar power available at night, so a substantial battery bank is required. For initial material and high installation costs.Lower solar production in the winter months. To use solar energy panels on the power grid, additional hardware (an inverter) is needed to convert direct electricity (DC) to alternating electricity (AC).In comparison to other renewable energy systems, the efficiency levels of solar panels are very low (14%–25%). As a result, solar energy is inconsistent and unpredictable, which reduces the reliability of solar panels as a solution[1] [15].

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