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Design and fabricate BRRI seed sower machine for mat-type seedling raising

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ABSTRACT

Manual method of seed sowing results in poor seed placement, low spacing efficiency, and severe back pain for the growers, which confines the size of field that can be planted. Uniform seedling density is essential for a mechanical rice transplanting system, which is complicated to maintain by hand broadcasting, a laborious and time-consuming operation. The research aims to design, develop, and fabricate a handy manually operated seed sower prototype using locally available raw materials for raising mat-type seedlings. The seed sower was designed, developed, and fabricated using a fluted roller and an adjustable soft-haired brush to disperse germinated paddy seeds uniformly. In the Farm Machinery and Postharvest Technology divisional research workshop of Bangladesh Rice Research Institute (BRRI), a rice seed sower machine was designed utilizing conveniently available components. The machine was fabricated as per design. Dispensing of seeds can be easily adjusted with neo-type levers marked from 0 to 7. A brush adjustment meter in 95 to 160g of sprouted seeds in each tray can adjust the seed delivery rate. The machine was calibrated for different sizes of germinated seeds. Optimal rice seeding rate is important in establishing a uniform stand with an adequate plant population. The results have shown that the capacity of the seed sower is 119 ± 5 trays per minute, whereas 50-60 trays per hour are broadcasted by in-hand broadcasting. The machine requires 41± 10 W of power to operate at 89% uniformity. *The machine is very useful for low cost and quick sowing of seeds uniformly in trays. Introducing a community-based seedling-raising method will help rural entrepreneurship development and rice transplanter machine adoption at the farmer level.*

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I. Introduction

Mechanical transplanting is being widely adopted in different parts of Bangladesh and seeing the benefits of the technology has received a huge response from the farmers. With the popularity of mechanical transplanters, seedling raising has become popular due to its better performance among rice farmers. If farmers are familiar with seedling-raising techniques, transplanters are available to them. In that case, timely transplanting can be ensured, and labor shortage will be mitigated during the peak transplanting period. Seed sowing is an important stage in rice transplanting and its mechanization directly affects rice productivity. Seed-to-seed distance, planting depth, soil covering, and soil compaction are all prerequisites for high yields that vary from crop to crop and in agro-climatic conditions (Abdulrahman and Kori, 2017). Therefore, it is essential to accelerate the mechanization of seedling raising to strengthen rice production capacity and speed up the rapid adoption of rice transplanter (Niua et al., 2014). The use of a transplanter requires growing seedlings in a precise way. Three types of seedling-raising modes are used in China: small seedlings raised in the greenhouse, intelligent seedlings grown in the greenhouse, and factory-grown seedlings, respectively (Niua et al., 2014). In Bangladesh, machine planting seedlings are usually produced in three ways, viz., dry and soft beds in polythene sheets and flexible and hard trays.

In most cases, mats or plastic trays are used to grow seedlings for mechanical transplanting. In addition, mat-type seedlings are currently being used for both manual and mechanical planting. Because the amount of land required for nursery seedlings can be reduced to about 100 sqm compared to ten times the area per hectare for root-washing seedlings (Bandi et al., 2020). Ratnayake and Balasoriya (2013) reported that rice transplanting is the most laborious and time-consuming task out of all stages of the rice production system. In this case, seedling-raising operation consumes about 25-28% of the total labor requirement for rice production. In another research report, Islam et al. (2016) mentioned that preparing seedling-raising activities for the mat-type system is mainly done manually in Bangladesh and requires 71-77 man-hours per ha. Seedlings should be raised with special care depending on proper seed soaking, disease disinfection, germination rate and media, characteristics, method of practice, and suitable seedling age. Healthy and vigorous seedlings with good formatted roots are used in the rice transplanter.

Quality seedlings permit better biological development of paddy plants for higher yield. In mechanical transplanting, the missing hill depends on the uniformity of seedlings and seedling number per unit area in the seedling tray (Shaikh et al., 2021). It is essential to produce mat-type seedlings by spreading some pre-germinated seeds evenly in trays, which is difficult to do manually. Polythene sheets or mats cannot be easily cut to the desired size to fit in the tray of a mechanical transplanter. But the seedlings taken in the tray can go directly to the transplanter tray because the seedling tray and the transplanter tray are the same sizes. Besides, seedling roots are not damaged in grown-up tray seedlings during transplanting. For mat-type seedlings, seeds cannot be spread manually at equal densities or uniformly and quickly, which affects the delayed adaption of the rice transplanter. The manual seed sower machine will overcome these constraints, but the machine is unavailable in Bangladesh. In this case, *a* seed-sowing machine is a good option to overcome the problem of manual seeding. Therefore, an effort was undertaken to create an appropriate seed-sowing device for planting pre-germinated rice seeds in seedling trays. The study aimed to design, develop and fabricate a manually operated seed sower with a performance test for mat-type seedling raising. To support the end-user, research and fabricate this machine and then hand it to local manufacturers to distribute to farmers and rural entrepreneurs.

II. Materials and Methods

Design Consideration

The design of the manually operated seed-sowing machine was completed with the help of CAD engineering tools (SolidWorks, 2020). The design specifications of the BRRI seed sower are shown in Table 01. The following design criteria or requirements were considered when designing the seed sower: (i) ease of sowing, (ii) easy and simple of operation and maintenance, (iii) light-weight and easy transport, (iv) locally available materials to fabricate the machine, (v) capability of dispensing various sizes of seed, (vi) ensuring the uniformity of seed distribution, (vii) avoiding the spilled seed on the tray (aero dynamics-falling rate-height of the seed meter), (viii) required hopper capacity, (ix) avoiding seed

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damage during rotation of the seed meter, (x) avoiding skidding while moving on the rail, (xi) ensuring the proper and accurate design of the seed metering device, (xii) strength of wheel to carry the overall weight of the machine, (xiii) facilitation of the powering of the machine through manpower, (xiv) ensuring that there is no seed escaping from hopper during seeding time, (xv) soft and flexible brush.

Table 01. Design specification of BRRI seed sower machine

Parameter	Unit
Name	BRRI seed sower machine
Model	BRRI SSM 2021
Dimensions (length × width × height), mm	775×350×280
Length of seed metering device, mm	590
Diameter of seed metering device, mm	40
Diameter of drive wheel, mm	80
Diameter of supporting wheel, mm	44
Brush length, mm	590
Brush width, mm	10
Machine weight, kg	16 kg
Power source for seed metering device	Manual
Sowing width, mm	580-590
Sowing speed, Trays/ seconds	2-3
Standard sowing amount (Sprouting paddy), g/tray	150-240

Description of the seed sower

The BRRI seed sower machine was developed and designed by the Farm Machinery and Postharvest Technology (FMPHT) Divisional Workshop of the Bangladesh Rice Research Institute (BRRI) in Gazipur, Bangladesh. The machine consists of a seed hopper, fluted roller seed metering device, drive wheels, and two supporting wheels on the front and back sides of the machine. The side cover was bent at the inner side at the supporting wheel position. Dispensing of seeds can be easily adjusted with the knob-type lever. The lever is attached to the hopper. There is a 0 to 7 position of the adjusting lever of the seeding hopper. The adjusting lever of the cover-up seed has 1 to 4 positions. The shutter lever is a group system to tension the friction system with seed hopper for easy to shift the lever at maximum and minimum hopper opening position for distributed seed, which is covered by a seed sower machine with a thickness of 6mm fine soil. Supporting wheels are positioned 15 mm in the inner side from the edge of the seed hopper (as shown in the paper) so that the driving wheel and supporting wheel come to contract to two edges of the rail for better traction. The clearance between the brush and seed metering device is 20 mm from the *bottomland* and 15 mm from the top land of the seed metering device, as maintained by the brush adjustment meter. The 3000 mm rail is divided into two equal parts that are made 1mm thick Mild Steel (MS) box and Teflon plastic is attached to one part of the rail to insert another part so that rails are easy to carry and set up.

Working principle of the machine

Human muscle power is applied to the machine body and divided into two directions, the first resists the front supporting wheel and the second rotates the two driving wheels. The machine started to move on when the force overcame the rolling resistance of the four wheels. A shaft of fluted roller seed metering device is connected with the drive wheels at the two ends so the wheels transfer rotary power to the metering device at the same ratio. The metering device discharged seed depending on wheel rotation and opening of the seed hopper.

Design of important components of the machine

Fluted roller seed metering device

The fluted roller could be formed without injuring the seed measurement mechanism's outer shell. Users can easily swap out the fluted roller for one with a varied number of teeth and groove depths, enabling the grain drill to sow various seeds or materials with various particle sizes, increasing the adaptability and versatility of the seed metering device (Minfeng et al., 2018).

Assuming a 100% degree of seed distribution, the number of grooves was determined by the equation given by Ryu and Kim (1998):

$n = 360\ Dsc/100\theta g$……………………………………………………………(1)

Where,

n= Number of grooves; θg= Open-angle of a groove (24°)

Dsc= Desired degree of scattering (above 90%)

From Eq. 2, which depicts the dispersion of seeds evenly spaced, 14 grooves were picked. To maintain the seed spacing and quantity along the row at a constant level, the roller speed must be increased if the number of grooves is decreased. High roller speeds, nevertheless, can harm seedlings and leave little time for loading seeds into the groove. Leave a 10 mm space between the roller's two sides to decrease the number of grooves and speed up the roller without mechanically harming the seeds. The roller had a 125.66 mm outside diameter. The groove measured 595 mm when g = 24°. Alternatively stated, the groove encompassed 24° of the 360° roller circumferences or 8.42 mm.

Determination of drive wheel diameter

The drive wheel diameter determines the rpm of a seed metering system; hence this is an important consideration. Amount of 160 g sprouted seed is required for a 580 x 280 mm^2 tray (Islam, 2017). Assume that each fluted roller seed meter groove can accommodate 10-12g of sprouting seed.

$$\text{No. of grooves required for covering tray} = \frac{\textit{Seed required per tray}}{\textit{Seed can hold in one grooves}} \quad \text{………………………(2)}$$

$$\text{No. of turn of seed meter required per tray} = \frac{\textit{No. of grooves required per tray}}{\textit{No. of grooves present in metering device}} \text{………(3)}$$

$$\text{Perimeter of drive wheel (mm)} = \frac{\textit{Width of tray}}{\textit{No. turn required per tray}} \text{…………………………………………(4)}$$

$$\text{Diameter of drive wheel (mm)} = \frac{\textit{Perimeter of drive wheel}}{\pi} \text{…………………………………………(5)}$$

Determination of hopper size by Sharma et al., *(*2019)

The volume of the seed hopper is given by

$V_b = 1.1\ V_s$ ……………………………………………………………………… (6)

Where,

V_b = Volume of the seed hopper, m^3 ; V_s = volume of seed, m^3

Also,

$V_s = W_s/\wp_s$……………………………………………………………………………(7)

Where,

Ws= weight of seed in the hopper, kg

$\wp_s$ = bulk density of sprouted seed, kg/m^3 = 428.5 kg/m^3 (Zareiforoush et al., 2011)

Putting, $V_s = W_s/\wp_s$ in equ. (7).

We get,

$V_b = 1.1\ W_s/\wp_s$

$= A \times B \times H_1 + \frac{1}{2} \times (A+B) \times H_2 \times L$ = Rectangular + Trapezoidal

Where,

For, rectangular shape A = length, m; B = Width, m; H_1 = Height, m and

For, Trapezoidal shape A = Top width, m; B = Based width, m; H_2 = Height, m L = Length, m.

The hopper form is related to the angle of repose of the seed and is an important design consideration for easy seed delivery. The angle of repose (Φ) was calculated using equation (1) (Gurjar et al., 2017).

$$\Phi = \tan^{-1}\left(\frac{2h}{d}\right) \quad \text{……………………… (8)}$$

Where,

Φ= Angle of repose (degree); h= height of bulk, (cm); d= Radius of bulk (cm)

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Figure 01. Determination of angle of repose of sprouted paddy seed

Here, the hopper wall slope should be greater than 38.5 degrees (Angle of repose of sprouted paddy seed)

Power requirement analysis

The driving wheel of the machine (made of rubber) encounters rotating resistance when rotating over the rail (steel). Rolling resistance is a measure of the impact of the rail surface on the wheel trade/rail interface. It measures the energy consumed per unit of distance rotating and is usually expressed in pounds. The coefficient of friction of rubber and metal is 1 (https://www.tribology-abc.com/abc/cof.htm).

Power required for move on the seed sower machine of rail using following Eqs. (Javidan & Mohamadzamani, 2021)

$$T_w = K_w \times W_t \times R_w \quad \text{......................} (9)$$

and

$$P = \frac{2\pi N T_w}{60} \quad \text{......................} (10)$$

Where,

T_w = the torque transmitted on the wheel (N-m)
K_w = the coefficient of the rolling resistance
W_t = the active weight of the machine (kg)
R_w = the radius of the ground wheel (m)
N =the speed of the shaft (rpm)
P = the power (W)

The fluted roller seed metering device's circumference was 125.66 mm. The groove was 595 mm long, having θg = 24° and an operational rpm of 81. Therefore, the power required to operate the seed metering device was 27.72 watts (Figure 02).

Figure 02. Determination of power requirement for the seed meter

Power required to carry the machine = Force × velocity = m × a × v ……………… (11)

For carrying the machine (Neglected creep load)
Where,

a = 9.8 m s^{-2}
P = power, W
v = Velocity, walking speed of man, ms^{-1}
m = Weight of machine + Weight of seeds, kg

Therefore, the power required to operate the machine = power required to move on the machine + power required to rotate the metering device.

The human body has limited power as a machine. The maximum power output of a healthy, vigorous, and adult human is about 900 watts which can last for a few seconds. In some contexts, this power output requires 300-500W and 600W of gross power for hoeing and tree felling, respectively (Fuller, 2012). A healthy, vigorous, and inspired worker can maintain an output of about 75 watts of power in 8-hour work shifts (Wikipedia, 2021).

$$\text{The sower machine consumed of human power} = \frac{\text{Power required to operate the machine}}{\text{Available human power}} \quad \text{.... (11)}$$

{for carrying the machine without considering creep load}
This clarifies that the seed sower machine is handy and easy to operate.

Performance test of the machine

The forward speed of seed sower

BRRI seed sower machine operated manually. The speed of the seed sower varies due to the variability of the operator's walking speed. The following equation (eq.12) was used to determine the forward speed of the machine.

$$S_s = \frac{d_s}{t_s} \quad \text{……………………....... (12)}$$

Where,

S_s = Forward speed, ms^{-1}
d_s = Travel distance, m
t_s =Required time, s

Table 02. Technical parameter of BRRI seed sower machine

Parameter	Unit
Open-angle of a groove	24°
Desired degree of scattering	above 90%
No. of groves in each fluted roller	14
No. of grooves required for covering each tray	13
No. of turn of seed meter required per tray	0.89
Perimeter of the drive wheel, mm	314.6
Diameter of the drive wheel, mm	100
Volume of the seed hopper, m^3	~ 0.03
Hopper dimensions (length × width × height), mm	600×260×245
Hopper angle of repose, degree	38.5
Torque transmitted on the wheel, N-m	1600
Speed of the shaft, rpm	81±5
Power required to operate the seed metering device, Watts	13.57 ± 5
Minimum power required to operate the machine, Watts	41±10
Forward speed, ms^{-1}	0.375

Seeding capacity
The seeding capacity of the seed sower was measured using equation 13.

$$S_c = \frac{N_t}{T_t} \quad \text{.....................................(13)}$$

Where,
S_c = Seeding capacity, no. min^{-1}
N_t = Number of trays in each travel, No.
T_t = Travelling time, min

Uniformity test of BRRI seed sower
The seeding meter was calibrated for each trial to get the recommended and uniform seed rate. Rice variety BRRI dhan87 was used to test the BRRI seed sower. Paddy was soaked in water for 24 hours and incubated for 24 hours. 10 (Ten) seedling trays with covered soil were arranged in a longitudinal line. Two rails were set up on both sides of the tray. The seed sower machine was run over the tray. Sample seeds were collected from the seedling tray marked 0.4m^2 box to measure the uniformity of seed placement. The uniformity of seed distribution was determined by counting the seeds per m^2 area of three replications. The uniform seed rate was maintained by adjusting the seed meter. The forward speed and adjusting lever were placed in such a position to maintain the recommended rate. The uniformity coefficient of distribution (UCD), which is the distributor's essential parameter, was calculated by Ziauddin and Khan (2001) using the formula the Catching Paper Box method.

$$UCD = 1 - \frac{\sum_{i=1}^{n}(x_i - \bar{X})^2}{nX} \quad \text{.................................(16)}$$

Where,
$\bar{x}$ = average weight of seeds of all boxes.
x_i = weight of seeds in each box; and
n = number of boxes kept for the test

III. Results and Discussion

Design of components and fabrication of the seed sowing machine
The fabrication of the first prototype was completed at the FMPHT divisional research workshop, BRRI (Figure 03).

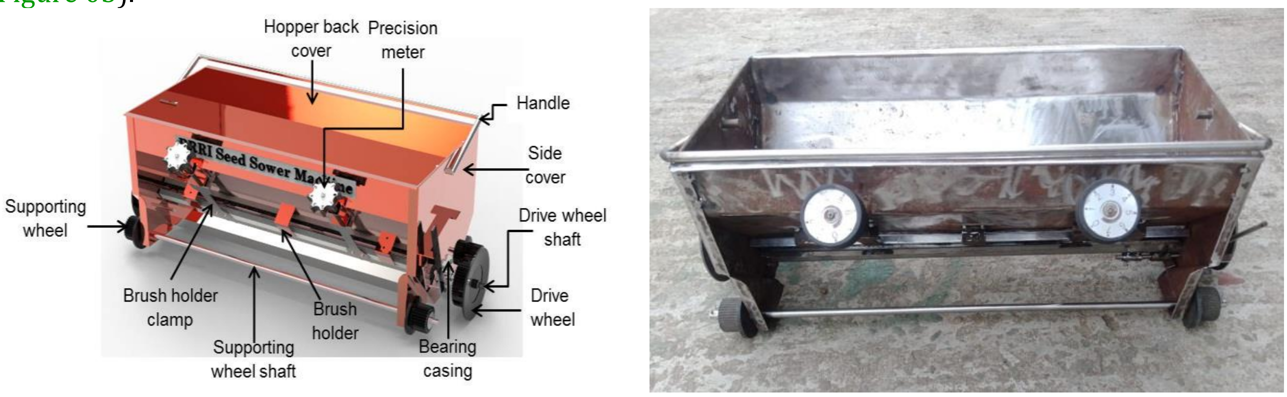

Figure 03. Complete assembly of seed sower (a) Isometric view, (b) Photographic view

Fabrication materials of the machine were selected considering important characteristics such as availability, strength, weight, durability, ability to cast, flexibility, corrosive resistance, machinability, electrical conductivity, and welded or hardened (Table 03). Then, the materials were collected from the local market following engineering design. Various activities, such as marking and cutting, bending, welding, grinding, and drilling were completed. Finally, assembling all the components and painting the machine were finished at the workshop. The bill of materials for the seed sower is shown in Table 04. Several fabrication faults of the first prototype were identified, and modification was done with redesigning in brush making.

Table 03. Selection criteria of fabrication material

Name of material	Reason for selection
Aluminum	Light Weight Corrosion Resistance Does not rust
Teflon plastic	Low coefficient of friction. High bulk density Low coefficient of friction.
PVC rubber	Easy to process and blend into both rigid and soft PVC materials Compatible with a variety of additives Resistant to grease, oil, and chemicals makes it effective for use in the automotive
Mild steel	Good ductility and weldability. High impact strength.
Stainless steel	Excellent corrosion resistance. Does not rust

Source: Velling, Andreas, 2020; AZO materials, 2002; AZO materials, 2005; AZO materials, 2013; Timco rubber, 2021; USPC (2009)

Table 04. Bill of materials of the seed sower machine

Components name	Description of components	Number of parts	Materials
Hopper side cover-1	Hold the metering device	2	AISI 1020
Hopper back-plate	Give the machine structure	1	AISI 1020
Hopper front plate	Give the machine structure	1	AISI 1020
Seed metering device	Dispose of seed from the hopper	1	AISI 2011
Brush adjustment meter	Regulate the brush opening	1	ASTM A36
Drive wheel	Drive the seed meter	2	Polypropylene
Seed adjustment metering clamp	Control seed delivery	1	ASTM A36
Brush holder	Holder of brush	1	AISI 316
Brush	Help smooth dispassion of seed	1	Hair
Supporting Wheel shaft	Holder of the supporting wheel	2	AISI 316
Supporting wheel	Balance the whole machine	4	Polypropylene
B18.22M - Plain washer, 10 mm, regular		4	---
Handle	Carry the machine	1	ASTM A36
PHT 4.2x10x8.6-slot-AB-N		9	---
Shutter lever	Regulate the hopper opening	1	AISI 316
Bearing casing	Bearing holder	2	AISI 1020

Hopper side cover

There are two side covers made with a 1 mm MS plain sheet. Each cover is 260 mm in length and 30 mm in width and 245 mm in height, having a 45 mm bore and two 10 mm drills for support of the metering device and supporting wheels, respectively. From the bottom edge points, 100 and 90 arms of two triangular plates bend at 15mm offset at the inner side (Figure 04).

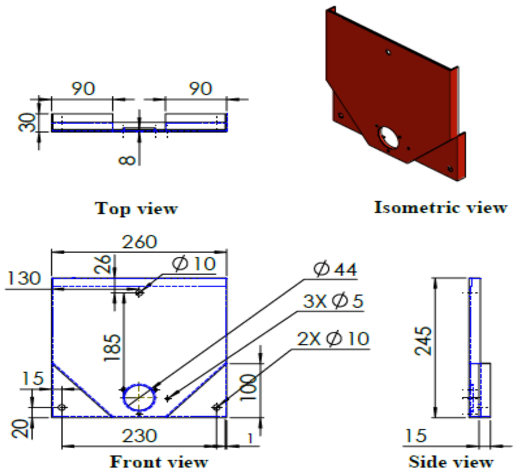

Figure 04. Drawing of side cover

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Supporting wheel

Four supporting wheels are made with Polypropylene material. The outer diameter of the wheel is 44 mm, the inner diameter is 10 mm, and the extended edge diameter is 63 mm and 25 mm in width (Figure 05).

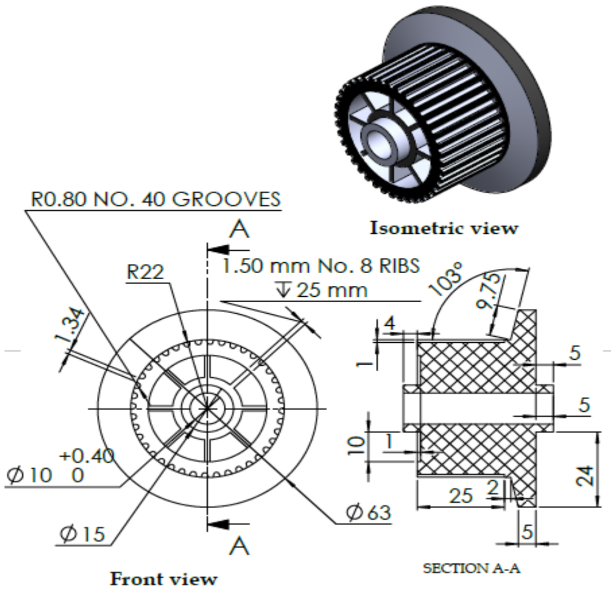

Figure 05. Drawing of supporting wheel

Drive wheel

Two driving wheels are made with Polypropylene material, the outer diameter of the wheel is 80 mm, the inner diameter is 10 mm, the extended edge diameter is 120 mm and the width is 32 mm. A rubber material was a wrap on the wheel for better traction (Figure 06).

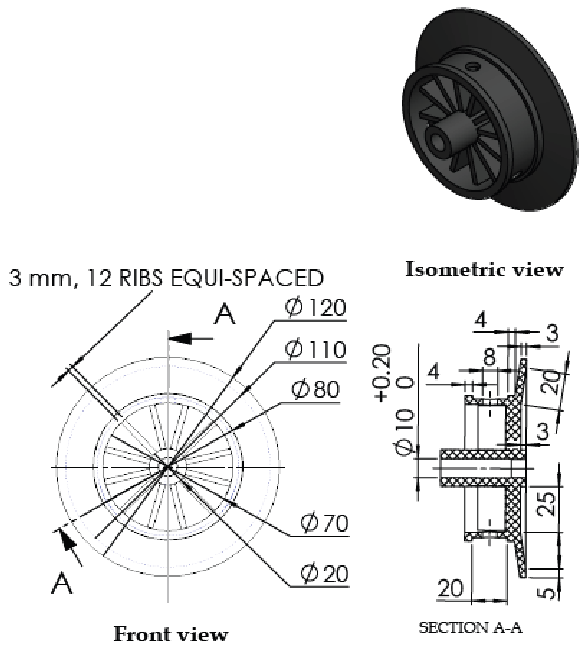

Figure 06. Drawing of the drive wheel

earing case

The bearing case is made of an MS plate. It holds the seed-metering device with seed carrying hopper (Figure 07).

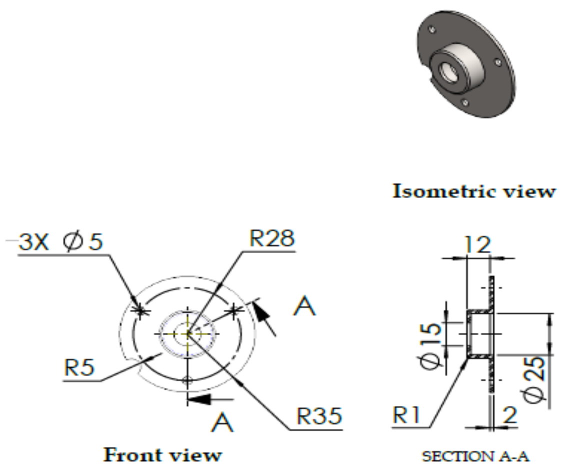

Figure 07. Drawing of bearing casing

Fluted roller seed metering device

Seed metering devices with fluted rollers are commonly used in the mechanical seeder. The metering device is made of an aluminum hollow shaft (40mm diameter). It is connected by a roller collar with two plastic wheels (595 mm in length) (Figure 08).

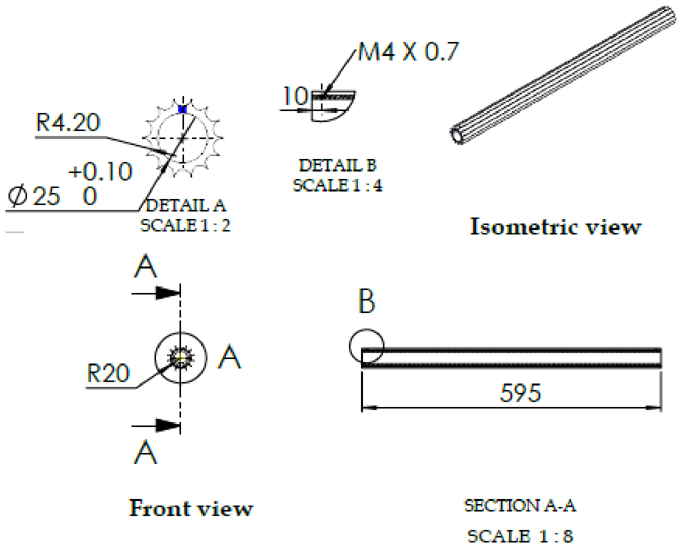

Figure 08. Drawing seed metering device with fluted roller

Brush

It is a very sensitive part of the machine (Figure 09). Sprouted seed is smoothly handled by this brush so the brush should be soft and flexible. The following design considerations were made for efficient functioning of this component: from hair to smooth disposal of seed, its length of 595 mm and height 35mm was chosen.

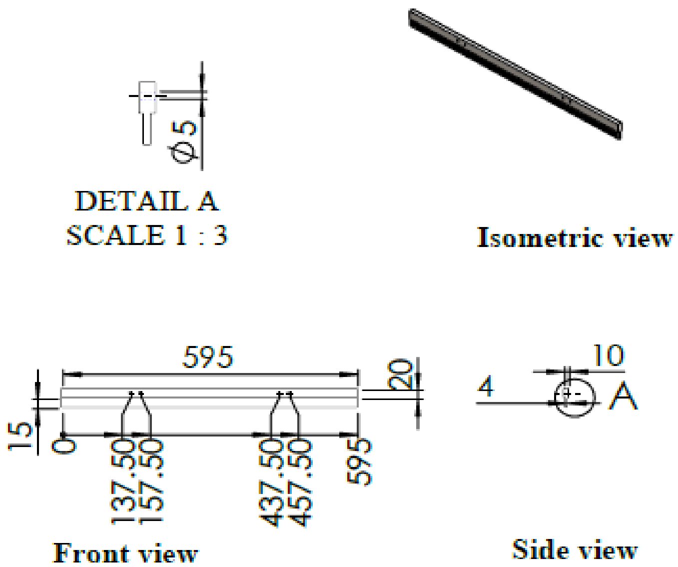

Figure 09. Drawing of brush

Brush adjustment meter

This is a controlling unit of seed by the variable opening size of the seed meter for different varieties of seeds (Figure 10). The 35 mm stroke length was chosen for seeding rate control and seed coverage.

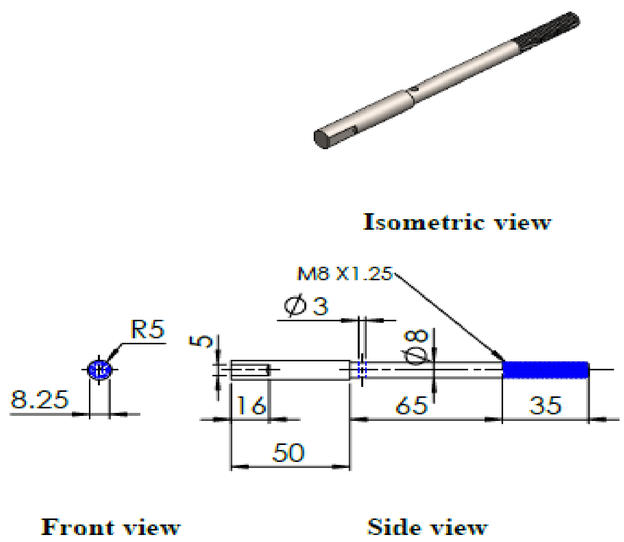

Figure 10. Drawing of brush adjustment meter

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The design mechanism has been completed considering the physical condition and desired requirements of the machine. The complete engineering drawing was finished to properly understand all components of the sowing machine (Figure 11). So, this device can distribute the required germinated seeds.

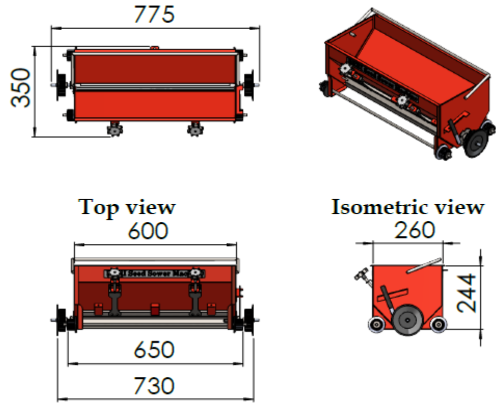

Figure 11. Overall dimensions of BRRI seed sower machine (dimensions are in mm)

Force applied to the machine

The average force angle considers 45^0 (Figure 12). When the force was applied to the machine at X distance from the middle wheel (drive wheel), the machine started to rotate about the drive wheel for the moment of $M_d = F*X$

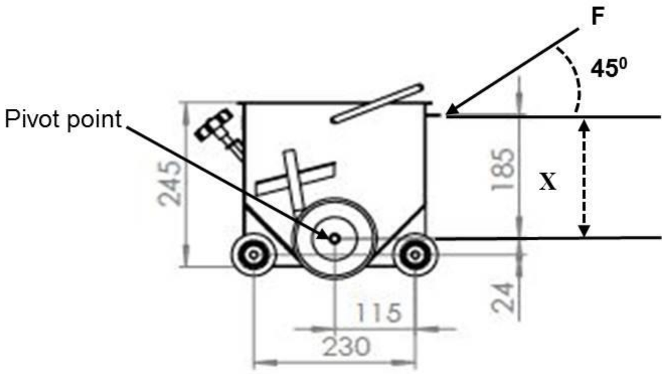

Figure 12. Illustration of the machine's various applied forces

When the front supporting wheel resist rotating the machine then the force 83.6 N force back on drive wheels (Figure 13) 228 ± 3 N is omitted for the ground support,62.6 ± 5 N-m is registered by the front supporting wheel.

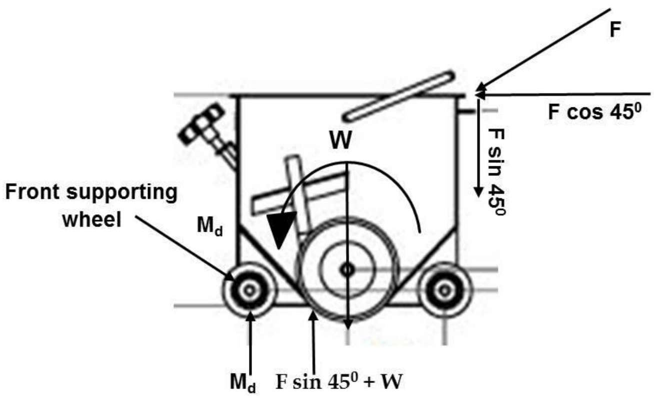

Figure 13. Display of the various applied resisted forces of the machine

Load analysis

Stress, strain displacement, and factor of safety were determined using static load analysis with 144.4 N force, 10 Nm torque, and 9.81 ms^{-2} gravity (Figure 14). A value known as the von Mises stress is used to predict whether a certain material will yield or fracture. Metals and other ductile materials are its main applications. According to the von Mises yield criterion, a material will yield if its von Mises stress under load is equal to or higher than its yield limit under simple tension. URES (Resultant Displacement) refers to the direction in which the model moves. It is not a true deformation because the deformation scale is 0.01. The actual distortion is one. However, use Simulation Xpress to ensure that this deformation cannot be altered. A safety factor of at least 1.5 to 3.0 is required by many rules. The material has failed if the factor of safety at a certain point is less than 1.0. The material at a place has only begun to fail if the factor of safety there is 1.0. A factor of safety greater than 1.0 at a place means that the material there is safe, as was the case here with a factor of safety of 3.

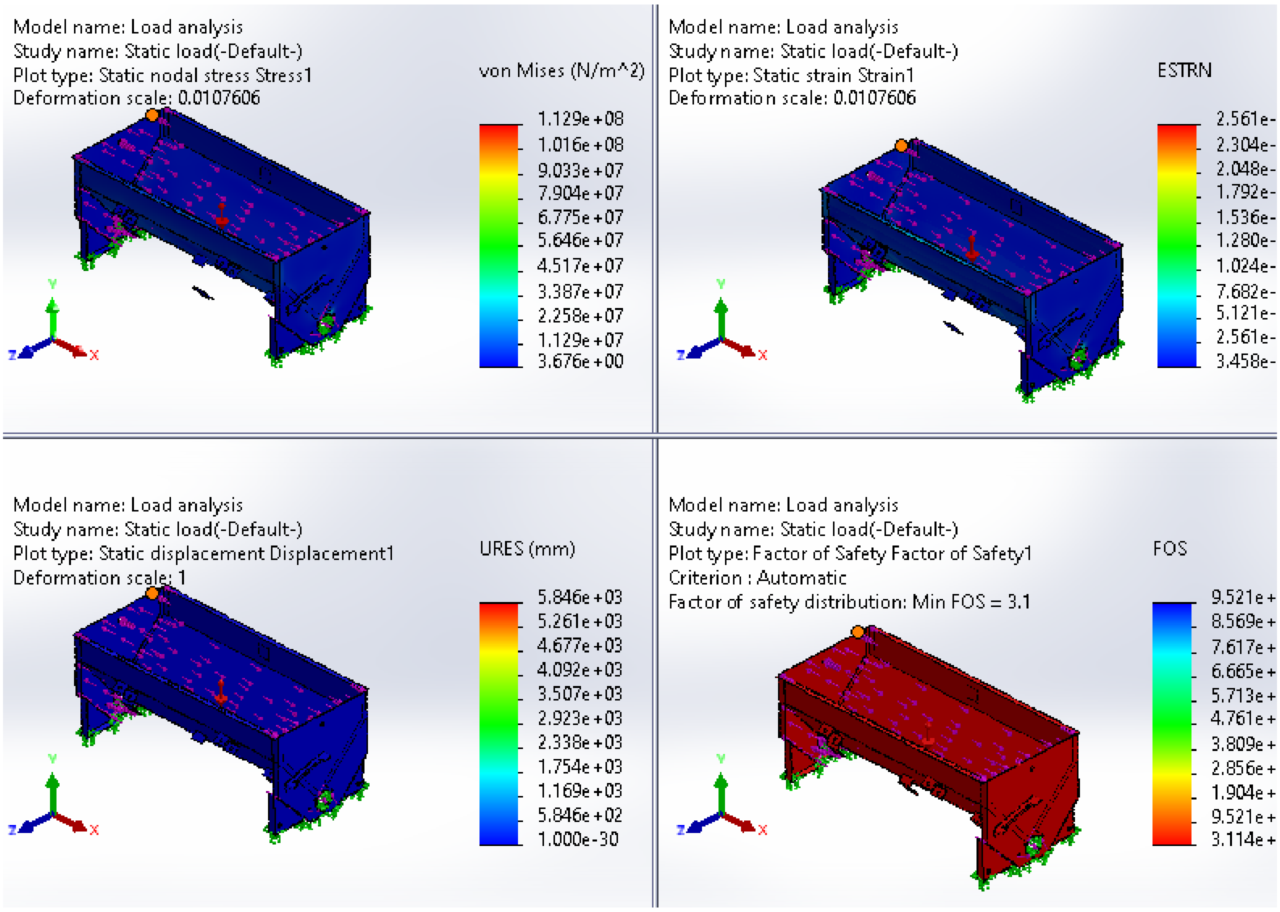

Figure 14. Load analysis of BRRI seed sower machine

Performance evaluation for seed sowing machine

The average seeding distribution capacity of the seed sowing machine was 119±5 tray per minute with a uniformity coefficient of distribution 89 % for forward speeds of 0.375 ms^{-1} during field test (Table 05).

Table 05. Field performance of seed sower machine

Parameter	Value
Forward speed, ms^{-1}	0.375
Capacity, Tray min^{-1}	119 ± 5
UCD %	89
Ger. rate%	About 96
Power required for seed meter, Watts	28 ± 2
Power required to move on the machine, Watts	14 ± 1
RPM of the drive wheel	81± 5
Hopper capacity, kg	8±1.5

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V. Conclusion

The BRRI seed sower machine was successfully developed and fabricated in the research workshop to spread seed uniformly to the seedling try in order to improve the performance of the rice transplanter machine. The capacity of the seed sower was found to be 119 trays per minute with a seeding uniformity of 89 %. The power needed to rotate the seed meter was 27.72 watts, and a 16 kg seed sower required 42 watts, per the results of the power requirements analysis. The BRRI seed sower had an easy-to-understand working concept and produced seedlings efficiently overall. The machine required about 119±5 trays per minute to disperse seeds for developing seedlings for rice transplanters, compared to 50–60 trays per hour when broadcasting by hand.

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Conflicts of Interest

Regarding the publishing of this research, the authors say they have no competing interests.

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