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Design, development and field evaluation of a tractor-operated ginger planter

Himanshu Shekhar Pandey[a*], Chetankumar Prakash Sawant[b] & Manish Kumar[b]

[a]ICAR- Indian Sugarcane Research Institute, Lucknow 226 002, Uttar Pradesh, India
[b]ICAR-Central Institute of Agricultural Engineering, Bhopal 462 038, Madhya Pradesh, India

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Ginger rhizome planting has been a challenge for farmers in India due to the lack of suitable machinery. Farmers have continued to rely on traditional planting methods, which is time-consuming, labour-intensive, and associated with significant human drudgery. Major ginger-growing states have often experienced labour shortages during the sowing season. To address this challenge, a tractor-operated ginger planter has been developed and evaluted at ICAR-Central Institute of Agricultural Engineering, Bhopal, for planting ginger seed rhizomes. The field tests results revealed that cup size, speed, and ginger seed grade significantly influenced the performance of the developed planter. As the cup size increased, the percentage of multiples have increased, while the percentage of missed seeds have decreased. The highest quality of feed index has been observed for graded seeds with cup size (A_2) at the forward speed of 2 km/h. The developed ginger rhizome planter is suiable to precise planting of seed rhizomes, with an effective field capacity of 0.25 ha/h. The labour requirement has been reduced by 76% compared to conventional methods of planting. Furthermore, the developed planter has cut the operational costs by 40% and significantly reduced the human drudgery involved in ginger planting operations.

Keywords: Automatic, Mechanization, Metering mechanism, Performance, Rhizome, Seed

1 Introduction

Ginger (*Zingiberofficinale Roscoe*) is a tropical monocotyledonous plant, valued for its uses as an herbaceous perennial[1]. India has historically been the leading producer, consumer, and exporter of spices worldwide. Ginger is grown in many states across India. However, the states of Karnataka, Orissa, Gujarat, Assam, Meghalaya, and Arunachal Pradesh collectively account for 65 percent of the country's total ginger production. Ginger is widely used as an immunity booster due to its antioxidant and anti-inflammatory properties. It also finds applications in a variety of industries, including food, beverages, cosmetics, and pharmaceuticals[2,3]. Agriculture is vital for ensuring food and nutritional security in India. Despite having only 2.3% of the world's total land area, India must ensure food security for 17.5% of the world's population, leading to significant pressure on land and fragmentation of holdings.

The adoption of agricultural mechanization in India is steadily increasing, enabling farmers to carry out agricultural activities with reduced drudgery and greater efficiency[4]. In India, during 2021-22 ginger is cultivated over approximately 0.21 million ha, produced around 2.5 million tonnes. The trends in production (Fig. 1) has steadily increased, starting from 0.702 million tons in 2010-11 and reached 2.33 million tons in 2023-24. Meanwhile, the area under cultivation shows minor fluctuations, ranging from 0.167 to 0.194 million hectares over the years[5,6]. Ginger is propagated using rhizomes, which are planted in a ridge and furrow system with row spacing of 30–60 cm, plant spacing of 20–30 cm, and a planting depth of 5–10 cm. However, planting ginger is a labour-intensive and time-consuming process. The shortage of labour during peak planting season, competition with other crop field operations, pose a significant challenge for farmers. Traditionally, ginger rhizomes are planted manually, requiring 200-250 man-h/ha where farmers dig shallow furrows with narrow spades, place rhizomes in the furrows, and cover them with soil. This method is not only tedious and time-consuming but also leading to increased drudgery[7]. As a result, farmers face increased labour costs, reducing the profitability of ginger cultivation. Mechanization offers a solution to this problem by reducing labour requirements, increasing productivity, and enhancing the overall efficiency of the planting

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[*] Corresponding author (E-mail: pandeyhs13@gmail.com)

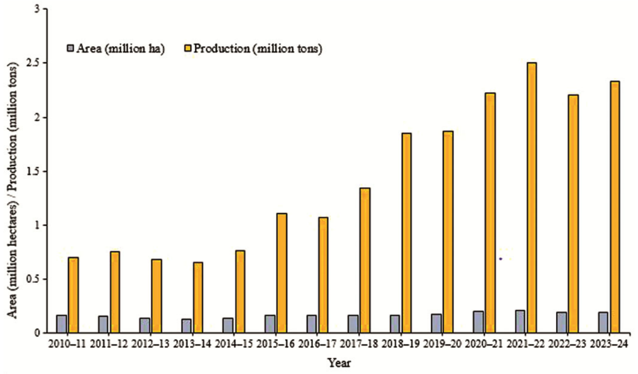

Fig. 1 — Area and production of ginger in India.

process. Previous studies have emphasized the need for technological interventions to minimize drudgery, improve production efficiency, and support economic growth[8,9]. The development of mechanized ginger planting systems can address these challenges by improving timeliness, reducing costs, and minimizing labour requirements. Moreover, mechanization can increase the area under ginger cultivation, leading to higher production levels[3]. Precision planting, an essential aspect of mechanized cultivation, ensures uniform row-to-row and seed-to-seed spacing, providing ample space for the proper growth of each plant. This also facilitates easier intercultural operations, ultimately resulting in higher yields and productivity[10]. At present, very limited ginger planting machines are developed that equipped with automatic seed metering mechanism. Existing planter designs lack the flexibility required to accommodate diverse crop-specific needs for achieving optimal planting configurations[10]. The planter with automatic metering mechanisms can enhance planting accuracy and uniformity, reduce labour requirements, and ultimately improve productivity and profitability in ginger cultivation[3,10]. In response to these challenges, efforts have been made to develop a tractor-operated automatic ginger planter to overcome the limitations of manual planting.

2 Materials and Methods

2.1 Description of tractor-operated ginger rhizome planter

A tractor-operated three-row ginger planter was designed and developed at the ICAR-Central Institute of Agricultural Engineering, Bhopal. The design of the machine components was based on operating principles, available power sources, and specific soil and crop requirements. Several factors related to planting materials and planter design were taken into account, as these significantly influence the planter's performance. The physical and engineering properties of the rhizomes, particularly their physical and mechanical characteristics, are crucial for determining the design specifications of an efficient mechanical planter taken into the consideration[3,11]. The planter was designed using CAD software (Pro/ENGINEER). The planter consists of a seed metering system, an agitator unit, a furrow opening unit, a ridge and furrow formation unit, and a power transmission system. An isometric view of the planter is presented in Fig. 2.

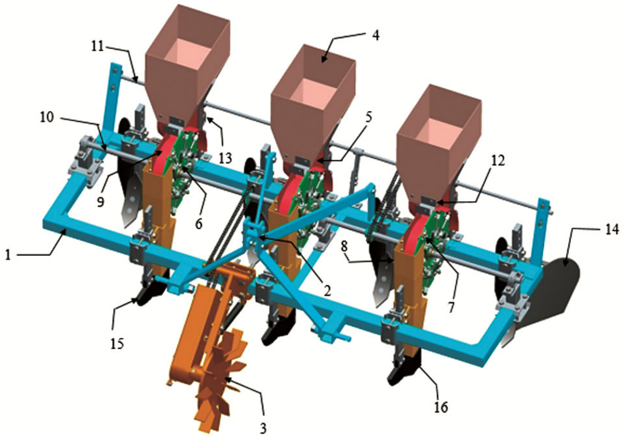

Fig. 2 — Prototype CAD model of designed tractor- operated ginger rhizome planter (1) main frame, (2) three-point hitch (3) ground wheel (4) seed box (5) seed metering chamber (6) seed metering disc (7) seed picking finger cup (8) cam actuator (9) seed delivery system (10) main shaft (11) agitator shaft (12) seed cut off mechanism (13) agitator (14) ridger bottom (15) furrow opener and (16) seed boot.

2.2 Design computations for the machine component

2.2.1 Design of seed metering system

The metering system consists of a vertical rotary seed metering disc, seed-picking fingers, actuating cam, and lever and spring assembly. The seed metering system was designed considering the key physical and engineering properties of ginger rhizome seeds. A schematic representation of the seed metering components is shown in Fig. 3.

The number of seed picking fingers on the metering cup (n) was determined[12].

Circumference of the ground wheel = π D = $\pi \times 0.40\ m = 1.26\ m$ assume 10 % slippage = 1.39 m

Number seed required in one revolution of ground wheel (Ns)

$$N_s = \frac{\pi \times D_g}{S_p} \qquad \ldots (1)$$

$$= 6.95$$

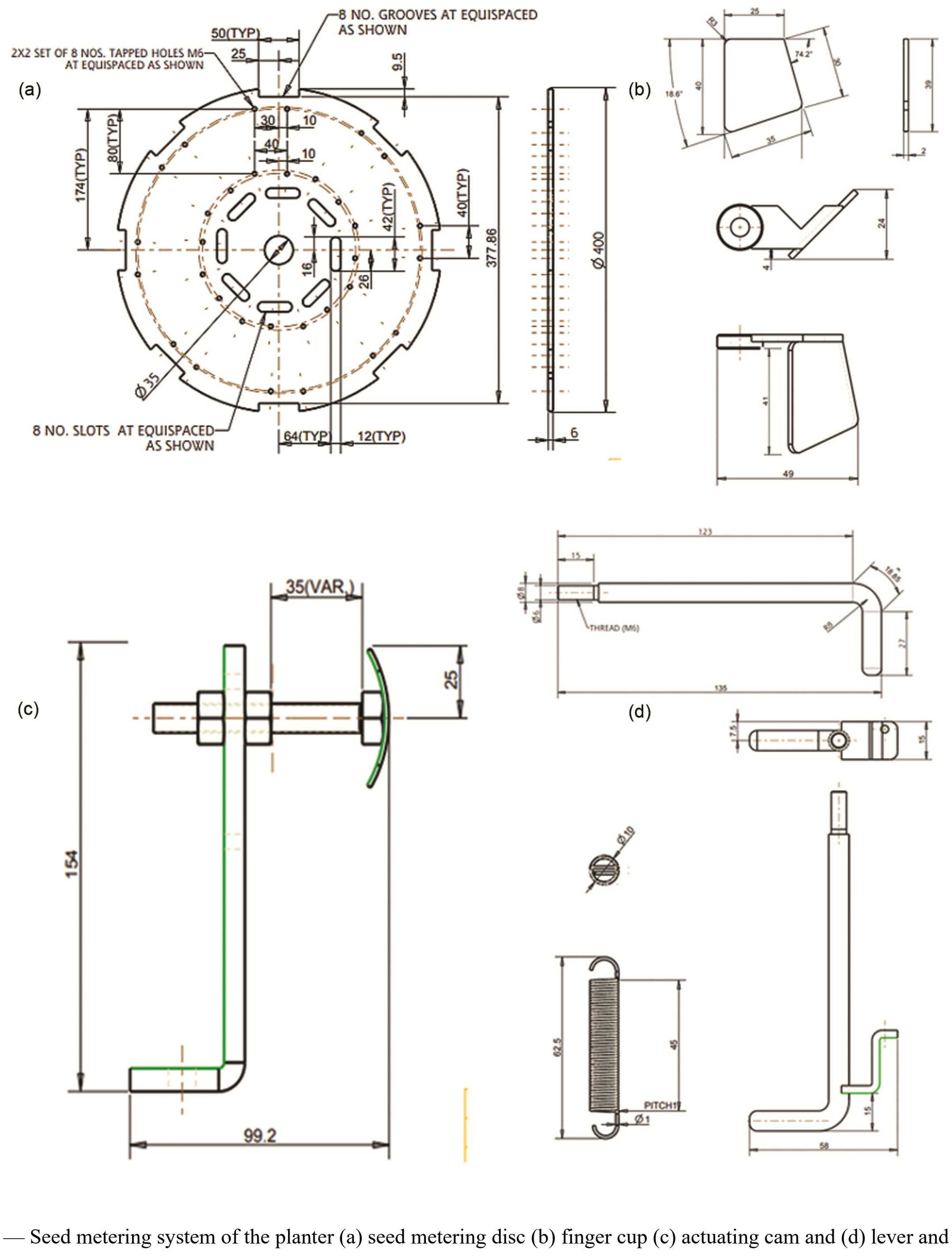

Fig. 3 — Seed metering system of the planter (a) seed metering disc (b) finger cup (c) actuating cam and (d) lever and spring.

Assumed 2.5 km/h maximum speed of tractor power unit.

$$V_g = \frac{2.5 \times 1000}{60} = 41.66$$

Where, V_g = speed in (m/min) V_m = speed of metering disc

$$\text{Speed ratio, } i = \frac{V_m}{V_g} \qquad \dots (2)$$

$$N_s = \frac{\pi \times D_g}{i \times S_p} \qquad \dots (3)$$

Where, N_s= Number of seed picking fingers, D_g= Diameter of ground wheel,

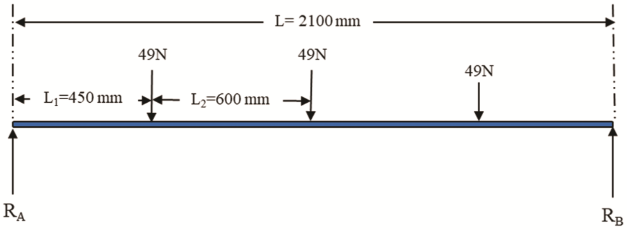

Fig. 4 — Dimensional view of shaft design.

S_p= plant spacing

i= transmission ratio

$$N_s = \frac{3.14 \times 0.4}{0.79 \times 0.20} = 7.95$$

Therefore, eight fingers were provided on the periphery of each seed metering disc.

2.2.2 Design of metering shaft

The design of the metering shaft was based on the use of ductile material (mild steel) whose strength is controlled by maximum shear stress. The metering shaft is supported at both ends with bearings and subjected to a combination of vertical forces and transmitted torque, due to vertical rotating metering disc loading and torque transmission resulting in both bending and torsional stresses as shown in Fig. 4. The shaft diameter was required to determine the load-carrying capacity of the shaft to ensure safe transmission[13]. The total vertical load acting on the shaft is:

$$R_A + R_B = 147 \text{ N} \quad \dots (4)$$

Taking moments about point A,

$$R_B \times 2100 = 154350 \text{ N-mm} \quad \dots (5)$$
$$= 73.5 \text{ N}$$

Therefore, bending moment at the centre of the shaft,

$$M = RA \times 1050 - 49 \times 600 = 47775 \text{ N-mm} \quad \dots (6)$$

Torque transmitted by shaft,

$$T = 9.8 \times 5 \times 0.20 \times 3 \quad \dots (7)$$
$$= 30 \text{ N-m}$$

For rotating shafts subjected to suddenly applied load with minor shocks because agricultural field operations involve non-ideal conditions (jerks, vibrations), therefore assumed shock and fatigue factors:

K_m = 1.5 and K_t = 1.5 and τ = 56 MPa (Khurmi and Gupta, 2015)

Equivalent torque,

$$T_e = \sqrt{(K_t \times T)^2 + (K_m \times M)^2} \quad \dots (8)$$

Using the torsional shear stress formula:

$$T_e = \frac{\pi}{16} \times \tau \times d^3 = 84{,}608 \text{ N-mm} \quad \dots (9)$$

Substituting, τ = 56 MPa

$$\text{Therefore} \quad d = \sqrt[3]{\frac{T_e \times 16}{\pi \times 56}} \quad \dots (10)$$
$$= 19 \text{ mm}$$

Considering a Factor of Safety (FOS) 1.5, the metering shaft diameter of 25 mm was selected to ensure structural integrity under the combined bending and torsional stresses.

2.2.3 Design of planter seed box

The seed hopper's material, capacity, and slope were designed based on the properties of the ginger rhizome seed[11].

$$\text{Number of plants required per ha} = \frac{10^8}{a \times b} = 83333 \text{ plants} \quad \dots (11)$$

where, a = row spacing, cm; b = plant spacing, cm

Theoretical seed rate

$$y = \frac{10^8}{a \times b \times p} \times \frac{x}{1000} \quad \dots (12)$$
$$= 1250 \text{ kg ha}^{-1}$$

Volume of the seed box required

$$v = \frac{y}{n \times \rho \times r}$$
$$= \frac{1250}{15 \times 648 \times 3} = 0.042 \text{ kg/m}^3 \quad \dots (13)$$

where, y = seed rate, kg ha^{-1}; x = average weight of a seed rhizome; n = number of seed box filling (assumed 15); r = number of seed box ; p = germination percentage, (assumed 1); ρ = bulk density of rhizome seed, 648 kg m^{-3} ; v= volume of seed box required

$$V_{upper(1)} = a_1 \times h_1 \times b \quad \dots (14)$$

$$V_{triangular(2)} = \frac{1}{2} a_1 \times h_1 \times b \quad \dots (15)$$

$$V_{lower\,(3)} = a_2 \times h \times b \quad \dots (16)$$

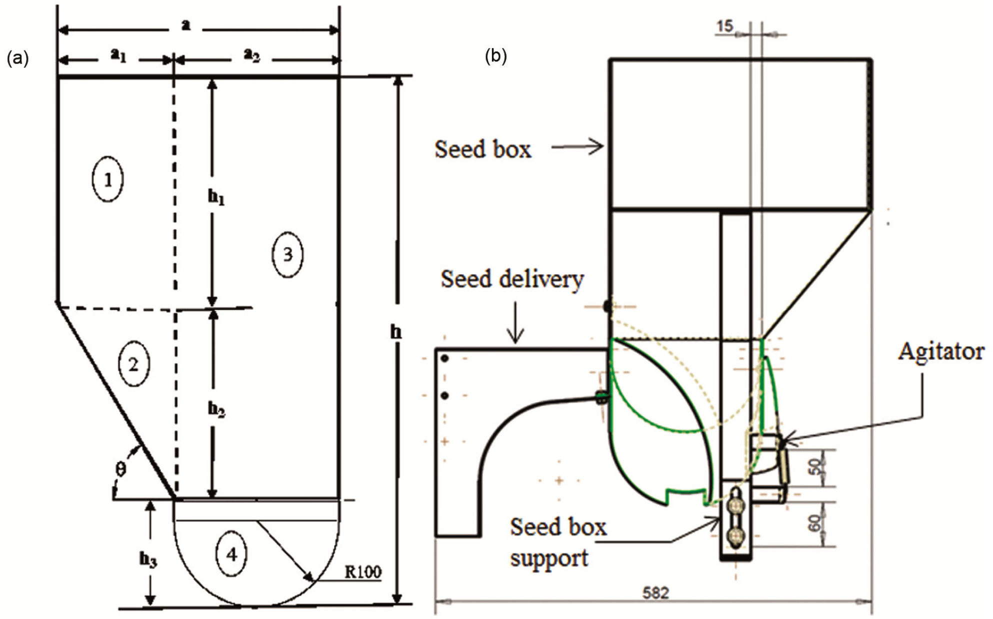

Fig. 5 — Schematic diagram of seed box of planter.

$$V_{\text{semi - circule}} = \frac{1}{2}\pi \times R^{2} \times \text{depth} \qquad \ldots (17)$$

Total volume of each seed box

$$V_{total} = V_{upper\,(1)} + V_{tringular\,(2)} + V_{lower\,(3)} + V_{semi\text{-}circle\,(4)} \ldots (18)$$

$$= 0.043\ m^{3}$$

Where, 1,2,3,4 is the seed box sections for calculations of total volume, a = width of seed box (348 mm); b= depth of seed box (250 mm); h= height of seed box (383 mm)

The seed box made of 1.6 mm thickness of MS sheet, sides are sloped gradually with an angle greater than the 42^{0} angle of repose (ɵ) of the rhizomes bulk to keep the continuous flow rate of rhizomes. A semicircular metering chamber 200 mm diameter and 126 mm height is made to receive ginger rhizomes from the main box as shown in Fig. 5.

2.2.4 Agitator

The agitator (seed pusher) has a dimension of 151.5×70 mm slanted to one side and equipped down of the secondary hopper at the rear side and actuates by the movement of the roller mounted on a common agitator shaft which gets power from the metering shaft to rotate. The rollers cam mechanism is arranged to help the agitator in pushing an individual rhizome into the picking cups (Fig. 6).

2.2.5 Design of Furrow openers

The runner-type furrow openers, one for each row were used to open the soil for the placement of seeds. The seeds from the metering mechanism were delivered through delivery tubes to the furrow opener.

2.2.5.1 The draft load on furrow opener (Df)

Specific soil resistance when sowing to a depth of 15 cm under heavy soils are 0.21 kg/cm^{2}.The soil resistance is assumed to be 3 to 5 times higher than actual average soil resistance.

$$D_{f} = 0.21 \times 3\left[\frac{(10+5)}{2}\right] \times 10 = 47.25\ k_{gf} \qquad \ldots (19)$$

For mild steel tynes we can take Factor of safety = 2.

Therefore, design draft of furrow opener would be

$= D_{f} \times$ factor of safety

$= 47.25 \times 2 = 94.5\ k_{gf}$ … (20)

2.2.5.2 Design of furrow openertine standard

Now, considering the furrow opener cantilever tine as a cantilever beam of 438 mm size fixed to the frame at one end[14].

Then, the maximum bending moment in the tine is given by,

M = Design draft (kg) × Beam span (cm)

= 94.5 × 43.8

= 4139kg-cm … (21)

Now, the section modulus of the tyne 'Z' is calculated as

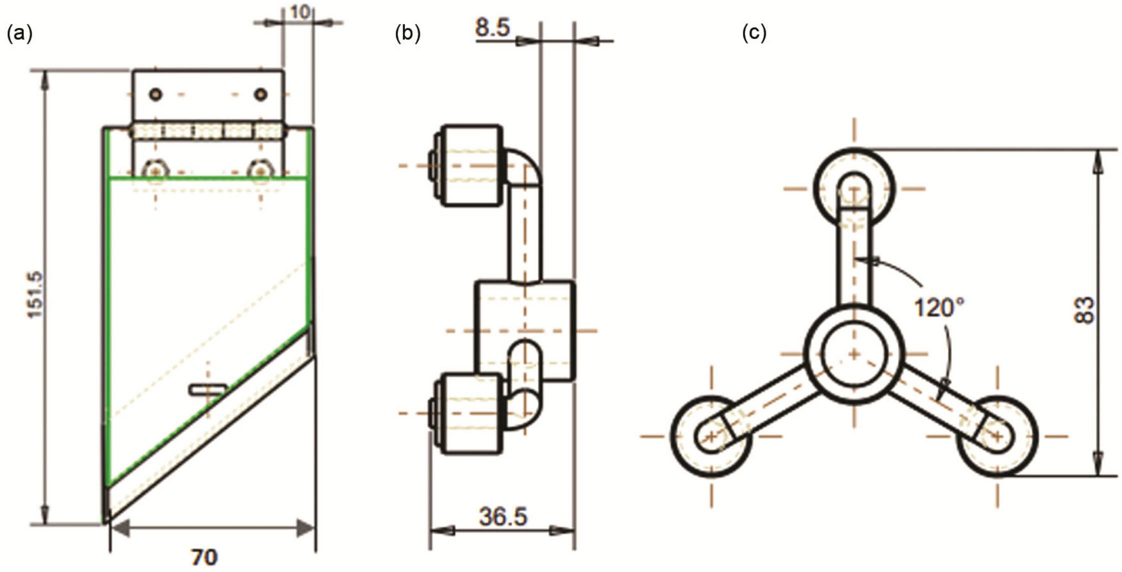

Fig. 6 — Agitator unit of the seed metering system (a) agitator or seed pusher, (b) roller cam front view and (c) roller cam side view.

σ_b is the bending stress in tine, kg/cm^2. We can take bending stress in mild

steel flat as 1000 kg/cm^{2}[15].

Then, for rectangular sections,

$$Z = \left[\frac{tb^2}{6}\right] \qquad \dots (22)$$

The ratio between the thickness to width (t: b) can be taken from 1: 3 to 1:4[11], $b = 3 \times t$

$$Z = t \times \frac{(4t)^2}{6} = \frac{16t^3}{6} \qquad \dots (23)$$

$$\text{Also, } Z = \frac{M}{\sigma_b} = 4.13$$

$$4.13 = \frac{16t^3}{6}$$

$t = 11.6mm$

$b = 11.6 \times 3 = 34.8$

Considering the factor of safety, therefore, cross section of the tyne= 13.92 × 50 mm. therefore selected MS flat 16×50 mm available for the construction of furrow opener standard of planter. The row spacing between the two furrow openers was 600 mm. The shank is made of mild steel 50 × 16 mm and the furrow opener was made of mild steel 140 mm × 100 mm × 20 mm size. The lower edge of the mild steel is slightly beveled (10 mm) to ensure an easier cut through the soil (Fig. 7).

2.2.6 Design of ridger bottom

The details of ridger type bottom, its tyne and various dimensions are given below[12]

$$R = \frac{h - \ell \operatorname{Sin}(\alpha)}{\operatorname{Cos}(\alpha)} \qquad \dots (24)$$

Where

R = Radius of curvature of bent portion of tyne (generally = 260 mm)

d = Maximum operating depth of ridger bottom, mm

ℓ = Breast length of shovel, mm

α= Rake angle, degrees

$b \times t$ = Cross section of tyne, mm^2 b = Width of tyne, mm

The draft load on ridger bottom tyne (D_f)

The force exerted on the ridger bottom is calculated as given below.

$$D_f = K_s \times W_f \times d_o \qquad \dots (25)$$

Where,

D_f= Draft on ridger bottom, kg or N

K_s = Specific soil resistance, kg/cm^2or N/cm^2

W_f = Width of furrow opener, cm

Do = depth of operation, cm

The furrow slice cut by ridger bottom will make the trapezoidal shaped furrow as shown in Fig. 8.

Now, the depth of operation of the ridger bottom of the furrow opened, w = 400 cm w_1 = 200 cm d = 320 cm, k = 0.41 kg/cm^2 [16]. Therefore, putting above design values in equation

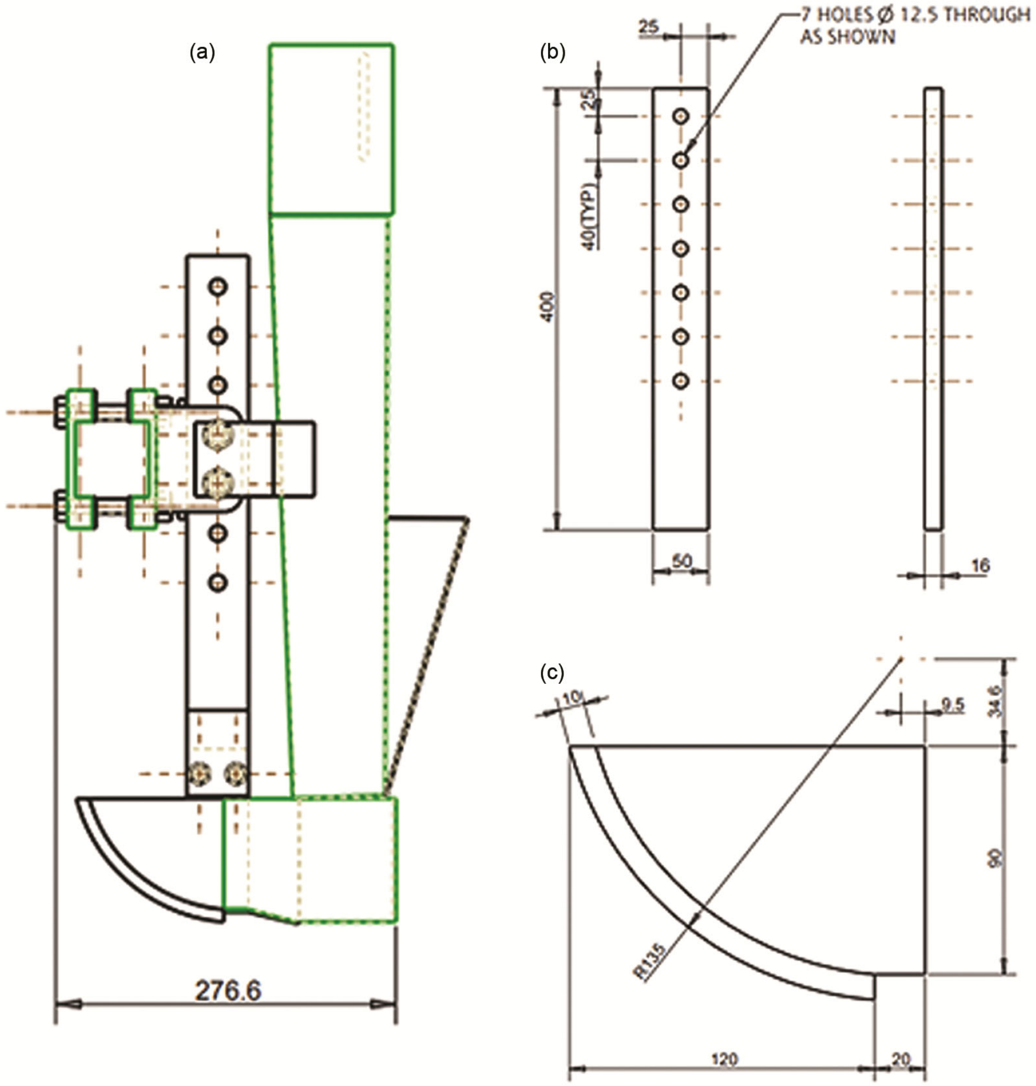

Fig. 7 — CAD drawing of furrow opener of the planter (a) furrow opener assembly, (b) furrow opener support (c) runner type furrow opener.

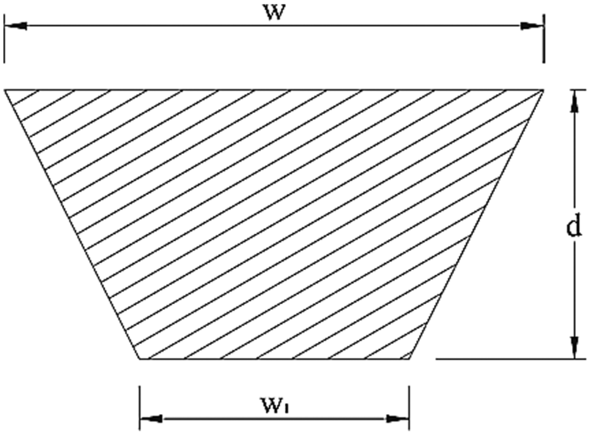

Fig. 8 — Section view of furrow cut of ridger.

$$D_f = 0.41\left[\frac{40+20}{2}\right]\times 20 \quad \ldots (26)$$

$D_f = 246.4$ kgf

Then, for mild steel tynes we can take factor of safety of 2 Therefore, the soil resistance encountered by ridger bottom is,

$= D_f \times$ factor of safety … (27)

$= 492$ kg_f

2.2.6.1 Design of ridger bottom tyne standard

Referring the Fig. 9 based on the findings the values considered are, h = 175 mm,

l = 250 mm, α= 65°. Therefore, putting values in equation, we get

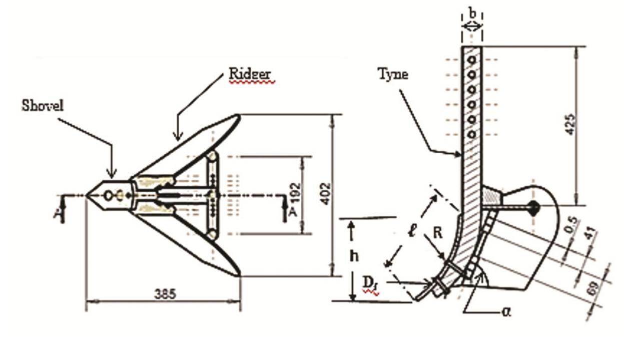

Fig. 9 — Ridger bottom of ginger planter.

$$R = \frac{175 - 130 \text{ Sin } (65)}{\text{Cos } (65)} \quad \dots (28)$$

= 135.3 mm, which is less than 260 mm

Now, considering the ridger bottom tyne as a cantilever beam of 575 mm size fixed to the frame at one end [14].

Then, the maximum bending moment in the tyne is given by,

M = Design draft (kg) × Beam span (cm)
= 492 × 57.5 … (29)
= 28290.75 kg-cm

Now, the section modulus of the tyne 'Z' is calculated as σb is the bending stress in tine, kg/cm^2. We can take bending stress in mild steel flat as 1000 kg/cm^{2}[15].

$$Z = \frac{t \times b^2}{6} \quad \dots (30)$$

Then, for rectangular sections, The ratio between the thickness to width (t: b) can be taken from 1: 3 to 1: 4, (Sharma and Mukesh, 2008) So, t : b = 1:2
b = 3 × t

$$\text{Therefore } Z = \frac{t \times 4t^2}{6} \quad \dots (31)$$

Also,

$$Z = \frac{M}{\sigma_b}$$

$$Z = \frac{M}{\sigma_b}$$

$$28.29 = \frac{6t^3}{6}$$

t = 2.17 cm = 21.8 mm b = 2 × 21.8 = 43.6 mm

Therefore, cross section of the tyne = 21.8 × 43.6 mm. So, we may take MS flat of 25 × 50 mm for the section size for the standard ridger support of the planter. The ridges are formed by the ridger wings, and the seeds placed during ridge formation. The soil thrown by the wings of the ridger covers the metered seed rhizomes. It makes the ridges up to 200 mm in height.

2.2.7 Design of power transmission system

The function of the power transmission system is to provide a drive from the drive wheel to all parts of the planter. The rotary motion of the ground wheel is transmitted to the intermediate shaft via a chain and sprocket mechanism, which helps reduce vibration and fluctuations. The agitator shaft is driven by the main shaft through an additional chain and sprocket system. The power is transmitted through the ground wheel to the seed-metering device with the help of set of chain and sprocket (Fig. 10).The speed of operation was considered to be 2.5 km/h (41.66 m/min).

Diameter of pegged ground wheel (D_g) = 0.40 m

Now for 2.5 km/h speed of power unit, the rpm of axle of pegged ground wheel is given by

$$Vg = \pi D_g N_g \quad \dots (32)$$

Where, Vg = speed in (m/min)
Dg = Ground wheel diameter, m
Ng = Ground wheel revolutions, rpm

2.2.8 Ground wheel

A ground wheel with lugged was used to provide drive to the seed metering mechanism. The ground wheel of 465 mm diameter and 50 mm width was fitted with 12 number of lugs on the periphery of the wheel for positive rotation. A spring was placed between the main frame and the wheel arm to keep the wheel pressed against the ground surface during the planting operation, helping to reduce wheel slip and prevent missing of seeds in the metering mechanism (Fig. 11a).

2.2.9 Main frame

The main frame serves as the skeletal structure of the planter, providing a platform for mounting other components. It was designed for its light weight and strength, making it durable enough to withstand the applied loads.The main frame of the machine was fabricated by using a mild steel square section (60×60×6 mm). It was equipped with provisions to attach the seed hopper, metering mechanism, power transmission system, and seed

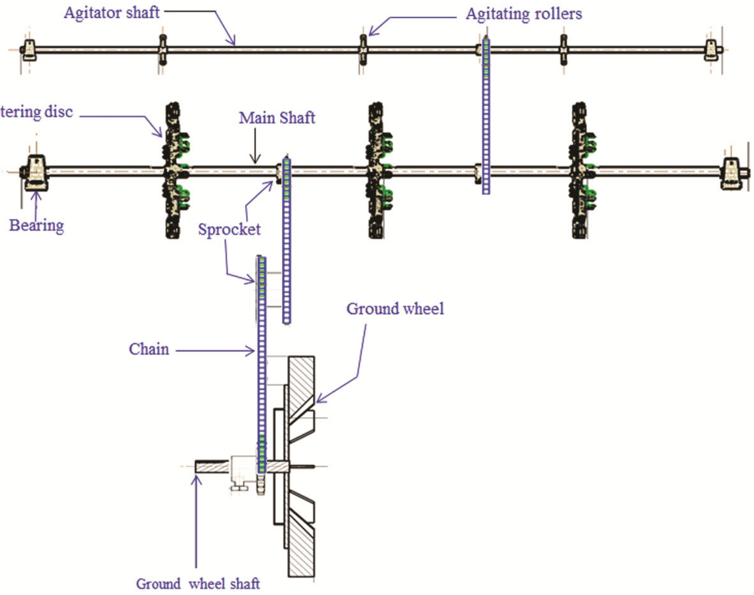

Fig. 10 — Power transmission system of the developed ginger planter.

placement furrow openers. The mainframe consists of a hitch unit which is used to connect a machine to the tractor (Fig. 11b).

2.3 Working principle of the developed planter

The working principle of the developed tractor-operated ginger rhizome planter is based on a precise and efficient mechanism for planting seed rhizomes in furrows. As the tractor moves forward, the ground wheel, in contact with the soil, rotates. This rotary motion is transferred to an intermediate shaft, which then drives the main metering shaft using a chain and sprocket system. Seed rhizomes are stored in the seed box, where they fall by gravity into the metering chamber equipped with an agitator located at the bottom of the chamber. The seed metering disc, mounted on the main shaft and fitted with seed-picking cups, is actuated by a cam. The agitator unit, enhances the delivery of seed rhizomes, ensuring they are properly fed to the picking cups. The metered rhizomes are then dropped through the seed delivery system into the furrow. Finally, ridgers, cover the rhizomes with soil, enables precise and uniform planting operation (Fig. 12). The detailed technical specifications of the planter is presented in Table 1.

2.4 Field evaluation of the planter

The experimental study was carried out at the Research Farm of ICAR–Central Institute of Agricultural Engineering, Bhopal, India, located at 23.1835°N latitude and 77.2410°E longitude, with an elevation of 495 meters above mean sea level, representing the agro-climatic conditions of Central India. The soil type at the experimental site is classified as Vertisols, comprising 34% sand, 22% silt, and 44% clay [17]. The field was prepared under a conventional tillage system to obtain a fairly flat field. The experimental area covered 0.5 ha, providing adequate area to evaluate the planter's performance under realistic field conditions, sufficient to accommodate multiple replications of each treatment for reliable data collection. The average moisture content of the soil was recorded as 12% (dry basis), indicating moderately dry conditions ideal for ginger rhizome planting, and the bulk density was recorded as 1.8 g/cm³. The experiment was laid out in a factorial randomized block design with three replications to evaluate the main and interaction effects among the selected variables and to ensure statistical significance (Table 2). The planter was operated for different operational speed, different size of cups and seed grades (G_1 and G_2). The graded rhizomes (G_1) are ginger rhizomes uniformly sized between 35–50 mm and weighing around 20 grams. Non-graded rhizomes (G_2) range from 25–65 mm, with weights between 15–30 grams, encompassing both smaller and larger pieces, leading to more variability in shapes. The experimental plan of the field performance study of the planter is presented in Table 2. The field performance parameters, including miss index, multiple index, quality of feed index, uniformity of seed spacing, field capacity, and field efficiency, were measured. A time utilization study [18]

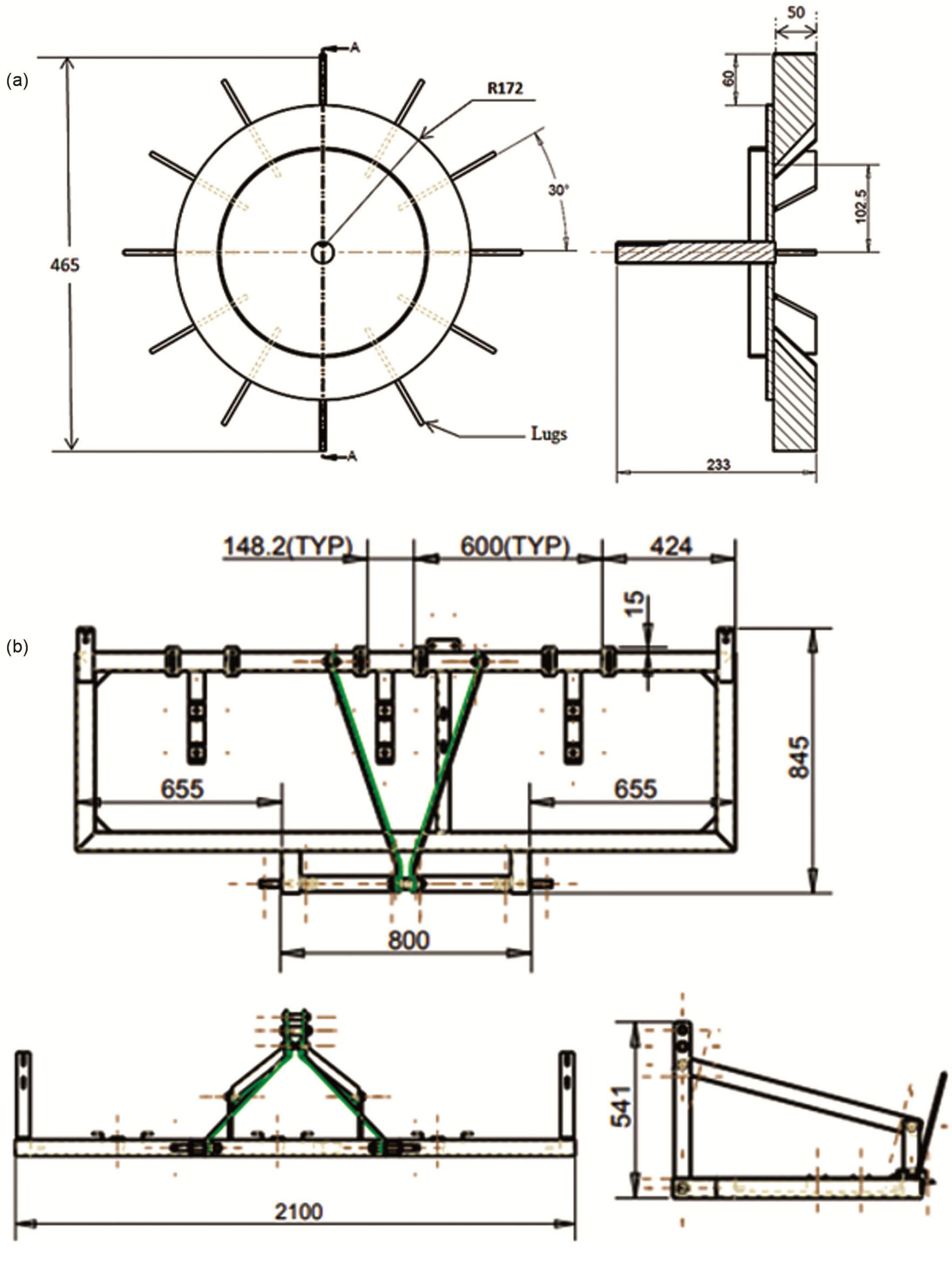

Fig. 11 — Schematic diagram of (a) ground wheel and (b) main frame of the planter.

was conducted to record the time used in different activities of ginger planting, including time lost in turning the planter at the headland, filling the seed hopper, and miscellaneous activities. The following mathematical relationships were used to analyze the performance results[3,19].

$$\text{Multiple Index} = \frac{N_1}{N} \quad \dots (33)$$

where, N = Total number of observations and N_1 = Number of spacing's in the region less than or equal to 0.5 times of the theoretical spacing.

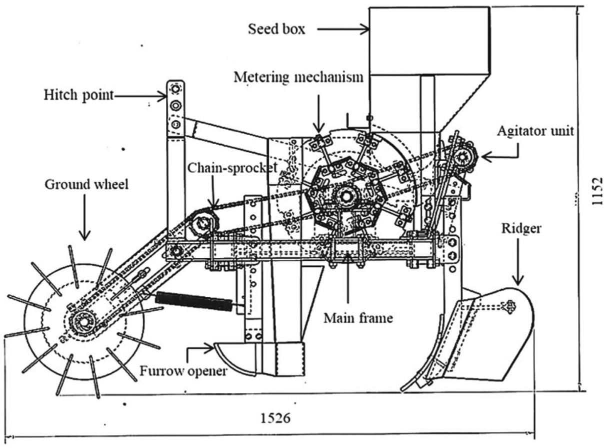

Fig. 12 — Schematic diagram of the developed ginger planter.

$$\text{Miss Index} = \frac{N_2}{N} \qquad \dots (34)$$

where, N = Total number of observations and N_2 = Number of spacing's in the region >1.5 times of the theoretical spacing

$$\text{Quality of Feed Index (QFI)} = \frac{N_3}{N} \qquad \dots (35)$$

where, N = Total number of observations, and N_3 = Number of spacing's between 0.5 times the theoretical spacing and 1.5 times of the theoretical spacing.

2.4.1 Uniformity of seed rhizomes spacing

The spacing between the seeds and the number of plants per hill were measured to analyze the uniformity of plant spacing[20]. The coefficient of variation and standard deviation were calculated by using following expressions.

$$SD = \sqrt{\frac{(Xi - X)^2)}{n}} \qquad \dots (36)$$

$$CV = \frac{SD}{X} \qquad \dots (37)$$

where, SD = standard deviation CV = coefficient of variation, %; n = total number of seeding actions Xi = ith spacing; X = Mean spacing.

Table 1 — Technical specification of the developed planter.

Sl. No.	Particular	Details
1.	Main frame	MS square pipe (60 mm × 60 mm × 6 mm)
	Overall dimensions	
	Length, mm	2202
	Width, mm	1405
	Height, mm	1152
3.	Metering mechanism	
	Type	Automatic
	Material	MS plate
	Diameter of disc, mm	400
	Thickness, mm	4
	Number of fingers on each disc	8
4	Furrow openers	
	Type	Runner type
	Material	MS plate
5.	Seed hopper	
	Material	MS sheet
	Dimensions, mm	348 × 250 × 610
	Capacity, kg	26
6.	Power transmission system	
	Type	Chain and sprocket
	Diameter of ground wheel, mm	400
	Speed reduction from ground wheel to metering shaft	01:00.8
	Speed reduction from metering shaft to agitator shaft	01:00.5
7.	Agitator unit	
	Material	MS rod
	Type	Vertical rotating
	No. of rollers	3
8.	Seed covering device	
	Type	Ridger
	Material	MS sheet
	Dimensions	402 × 385 × 680
9.	Weight, kg	288

2.4.2 Effective field capacity

During field tests, time losses for every event viz,, refilling of rhizomes in the planter, and turning losses were recorded. To calculate the effective field capacity (ha/h), the time spent on effective work, as well as time losses due to activities such as turning and refilling the rhizomes, were recorded[21].

$$E_{fc} = \frac{A}{T_p + T_n} \qquad \dots (38)$$

Where,

E_{fc} = Effective field capacity, ha/h

A = Area covered, ha

T_p= Productive time, h

T_n = Non-productive time, h

2.4.3 Field efficiency

Field efficiency (E_f) was expressed as percentage and measured by using below formula,

$$FC = \frac{\text{Effective field capacity, ha/h}}{\text{Theoretical field capacity, ha/h}} \quad \dots (39)$$

2.4.4 Draft Measurements

The draft of the developed planter was measured using a 3-point hitch dynamometer, which incorporated three half-bridge load cells at all three connection points between the planter and the tractor. Non-linearity, non-repeatability and hysteresis were ±0.01, 0.01 and 0.005 of rated output.

2.5 Statistical analysis

The data were statistically analyzed using a Factorial Completely Randomized Design (FCRD) with SAS 9.3 software. The analysis of variance (ANOVA) tables for different parameters were tabulated and the level of significance is reported.

Table 2 — Experimental plan of the field performance study of the planter.

Sl. No.	Variables	Level
1	Forward speed of tractor	S_1 =1.5 km/h, S_2= 2 km/h, S_3 =2.5 km/h
2	Cup size	A_1=25 mm, A_2=35 mm, $A_{3=}$ 45 mm
3.	Seed type	G_1= Graded rhizome (35-50 mm), G_2= Non- graded rhizome (25–65 mm)

2.6 Economic analysis

The total cost of planting operation was analyzed by adding the fixed and variable cost of the tractor and planter. The parameters used in the analysis of cost components were derived either from the actual performance data of the planter or based on the Bureau of Indian Standards for estimating the cost of farm machinery operations[21].

3 Results and Discussion

3.1 Effect of operational parameters on seed spacing

The ANOVA Table 3 present that the overall model is significant ($p<0.001$), indicating it a considerable amount of the variation in the seed spacing's. The speed of operation, cup size, and seed grade had a significant effect on seed spacing at the 1% level of significance. The combined effect of cup size and seed grade was also significant at the 5% level. However, the interaction between all three factors was found to be non-significant. Fig. 13 shows that the graded seeds maintained uniform spacing, ranging from 180 to 200 mm, with an average of 225 mm whereas, non-graded seeds showed variability, ranging from 230 to 350 mm, with an average of 288.5 mm, showing reduced uniformity at higher speeds. The higher speeds and larger cup sizes contribute to wider spacing, with the most significant increase observed at the highest speed and largest cup size. As the speed of the planter increases, the seed spacing tends to become more non-uniform. This is because at higher speeds, the metering mechanism has less time to accurately pick and drop each seed at the

Table 3 — Analysis of variance (ANOVA) of speed of operation, cup size and seed grade, on seed spacing.

Source	DF	Type III SS	Mean Square	F Value	Pr> F
Corrected Model	17	278.47	16.96	5.98	$<0.001^{**}$
Intercept	1	10524.72	10524.72	370.76	$<0.001^{**}$
Speed (S)	2	42.17	21.08	7.41	0.002^{**}
Cup size (A)	2	24.97	24.97	8.76	0.009^{**}
Seed grade (G)	1	103.8	103.8	36.43	<0.001*
Speed × Cup size	4	12.45	6.23	2.21	0.131^{NS}
Speed × Seed grade	2	13.56	6.78	2.39	0.12^{NS}
Cup Size × Seed grade	2	13.82	13.82	4.85	0.041^{*}
Speed × Cup size × Seed grade	4	16	8	2.81	0.085^{NS}
Error	20	51.29	2.85		
Total	37	4051.44			
Corrected Total	37	329.76			

**= Significant at 1% level, *= Significant at 5% level ^{NS}= Non-significant

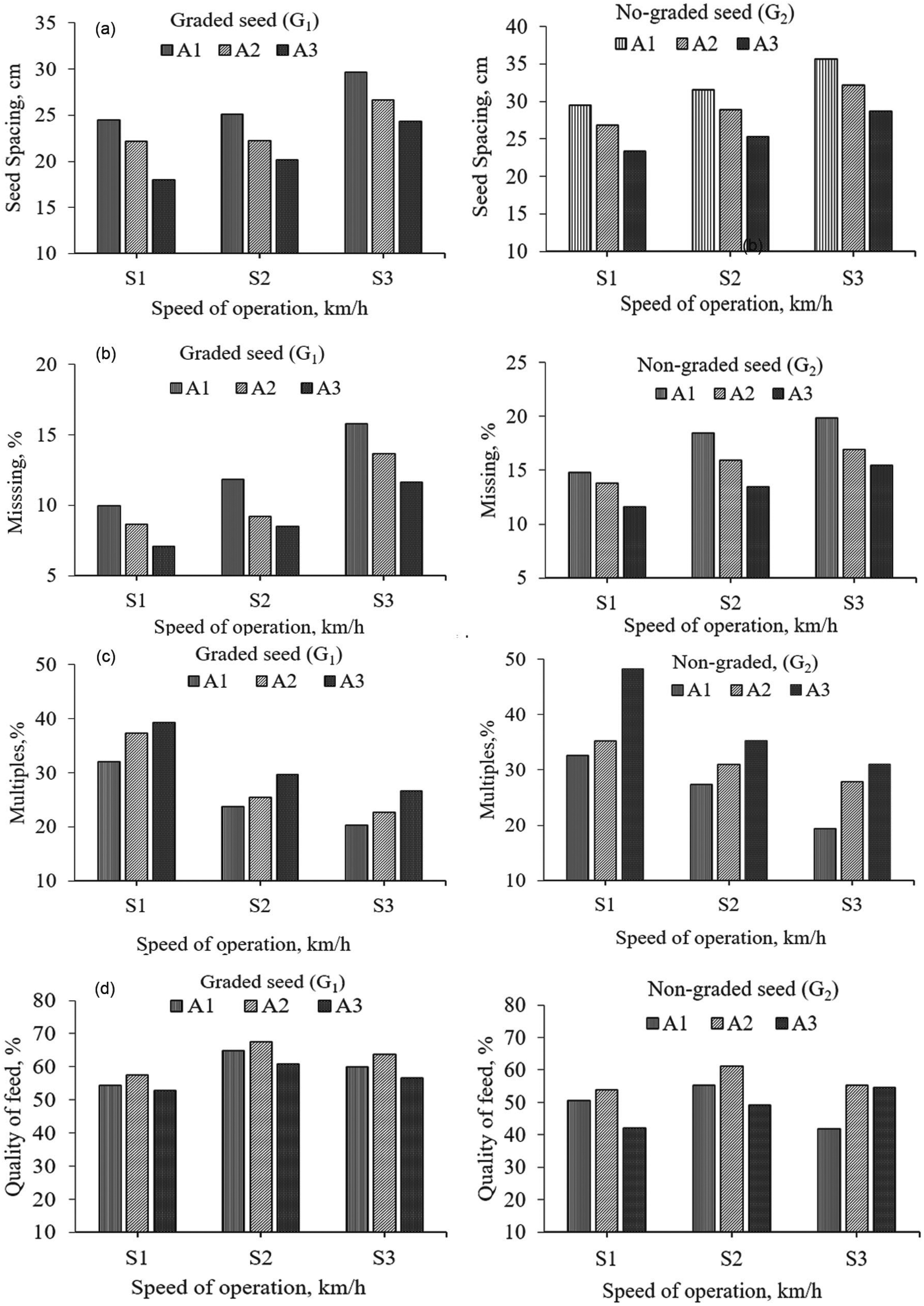

Fig. 13 — Field performance indices (a) spacing (b) missing, (c) multiple and (d) QFI of the planter.

correct interval. The larger cup sizes led to less precise seed spacing due to their capacity to hold more than one seed, which resulted in multiple seed drops. Smaller cups generally improved spacing precision by holding a single seed per cup. The graded seeds (uniform in size and shape) resulted in more uniform seed spacing closer to theoretical spacing of 200 mm because they fit more predictably into the picking fingers. Non-graded seeds, being of varying sizes, were more likely to cause non-uniform spacing.

3.2 Effect of operational parameters on missing seeds index

The ANOVA Table 4 presents the effect of speed of operation, cup size, and seed grade on the missing index. The corrected model is significant ($p<0.001$), indicating it a considerable amount of the variation in the missing index. The speed of operation, cup size, and seed grade had a significant effect on missing at the 1% and 5% level of significance. However, interactions between factors were found non-significant. Fig. 13 shows the missing values for various combinations of speeds, cup sizes, and grades. The lowest missing percentage was observed at S_1 speed of operation with A_3 cup size for graded seed. The highest missing percentage for the speed of S_3 was observed as 19.88 % whereas the lowest of 7.06% at the speed of S_1. The higher speed of operation generally leads to higher missing values while decreases as the cup size increases. This suggests that larger cups pick more seed effectively, leading to fewer missed seeds. The trend of lower missing index with larger cup sizes is consistent across different speeds and grades. The higher speed of operation increased the missing as seeds are more likely to skip due to insufficient time for the cups to pick and drop the seeds properly. Smaller cups missed seeds more frequently as the seeds were large or irregular in size, while larger cups might reduce the missing index but increase the multiples. Non-graded seeds are more likely to cause a higher missing index because the variability in seed size can lead to empty or improperly seed pick-up by fingers. Graded seeds had lower the missing index. Similar result also reported by other researchers[22,23].

3.3 Effect of operational parameters on multiple index

The ANOVA Table 5 presents that the influence of operational parameters on the multiple seeds. The speed of operation, cup size, and seed grade had a significant effect on multiples at the 1% and 5% level of significance. The combined effect of cup size, and seed grade had a significant effect on multiples at the 5% level of significance, however, interactions effect of other factors were found non-significant. The model explains 88.3% of the variance, demonstrating a strong fit. Fig. 13 shows the average multiple index values for different combinations of speed, cup size, and seed grade. The higher cup sizes and speed of operation generally lead to higher multiples. The highest multiples values of 48.33 % were observed at the forward speed of S_1 with A_3 cup size for non-graded seeds whereas the lowest 20.33 at the forward speed of S_3 with A_1 cup size for non-graded seeds. At higher operational speed of planter, the metering mechanism was delivering multiple seeds in one spot, particularly the cups were unable to release seeds evenly. The larger cup sizes were more likely to cause

Table 4 — Analysis of Variance (ANOVA) of speed of operation, cup size, and seed grade on missing index.

Source	DF	Type III SS	Mean Square	F Value	Pr> F
Corrected Model	17	1122.68	66.03	10.25	<0.001**
Intercept	1	3524.12	3524.12	539.42	<0.001**
Speed (S)	2	104.9	52.45	7.77	0.002**
Cup size (A)	2	40.15	40.15	5.94	0.021*
Seed grade (G)	1	98.35	98.35	14.58	0.001**
Speed × Cup size	4	27.52	13.76	2.04	0.144NS
Speed × Seed grade	2	23.85	11.93	1.77	0.195NS
Cup Size × Seed grade	2	60.24	60.24	8.94	0.046*
Speed × Cup size × Seed grade	4	18.43	9.22	1.37	0.272NS
Error	20	119.43	6.64		
Total	37	1754.24			
Corrected Total	37	1242.11			

**= Significant at 1% level, *= Significant at 5% level NS= Non-significant

Table 5 — Analysis of Variance (ANOVA) of speed of operation, cup size, and seed grade on multiple index.

Source	DF	Type III SS	Mean Square	F Value	Pr> F
Corrected Model	17	586.82	34.52	8.16	<0.001**
Intercept	1	13054.96	13054.96	309.22	<0.001**
Speed (S)	2	57.12	28.56	6.66	0.006**
Cup size (A)	2	23.24	23.24	5.38	0.038*
Seed grade (G)	1	108.74	108.74	25.37	<0.001**
Speed × Cup size	4	29.36	14.68	3.41	0.062^{NS}
Speed × Seed grade	2	18.22	9.11	2.11	0.144^{NS}
Cup Size × Seed grade	2	31.45	31.45	7.31	0.015*
Speed × Cup size × Seed grade	4	29.4	14.7	3.39	0.056^{NS}
Error	20	78.01	4.33		
Total	37	1429.84			
Corrected Total	37	664.83			

**= Significant at 1% level, *= Significant at 5% level ^{NS}= Non-significant

Table 6 — Analysis of Variance (ANOVA) of speed of operation, cup size, and seed grade on the percent value of quality of feed.

Source	DF	Type III SS	Mean Square	F Value	Pr> F
Corrected Model	17	4460.89	262.41	8.45	<0.001**
Intercept	1	38787.66	38787.66	125.47	<0.001**
Speed (S)	2	2053.6	1026.8	13.25	<0.001**
Cup size (A)	2	1209.36	604.68	6.68	0.009**
Seed grade (G)	1	2586.1	2586.1	9.9	0.006**
Speed × Cup size	4	1121.05	280.26	8.92	0.001**
Speed × Seed grade	2	450	225	3.13	0.069^{NS}
Cup Size × Seed grade	2	380.2	190.1	1.85	0.19^{NS}
Speed × Cup size × Seed grade	4	250	62.5	1.25	0.337^{NS}
Error	20	4934.36	246.72		
Total	37	95023			
Corrected Total	37	9395.27			

**= Significant at 1% level, *= Significant at 5% level ^{NS}= Non-significant

multiple seed drops, especially cup can pick more than one seed at a time, leading to clumping. The multiple seeds in non-graded seeds increased due to smaller seeds potentially being picked up in larger quantities by the fingers whereas, the uniformly graded seeds, were less likely to pick more than one seed. The increase in multiples may be due to some seeds also moving/riding in between two seeds. Similar result also reported by other researchers [22,23,24].

3.4 Effect of operational parameters on seed quality of feed index

The quality of feed index is an important indicator that measures the accuracy with which seeds or planting material are placed into the soil by the planter. It is used to assess the efficiency of the planter in delivering seeds accurately, which is essential for optimal plant growth and crop yield. The ANOVA Table 6 presents the effect of various operational parameters on the quality of feed index (QFI). The overall model is highly significant ($p<0.001$), a significant variation in the QFI. The speed of operation, cup size, and seed grade had a significant effect on missing at the 1% and 5% level of significance. The interaction between speed and cup size is also significant ($p = 0.001$), suggesting their combined effect influences the QFI. However, interactions between other factors and the three-way interaction were non-significant. Fig. 13 shows at operational speed $S_2$the QFI is highest ranging from 63.83 to 67.45% with graded seeds. The speed S_3 has lower QFI values (48.70 to 61.76%), for non-graded seeds but significantly higher values for graded seeds. This indicates that higher speeds generally reduce QFI, but larger cup sizes and specific grades can influence QFI. The highest average QFI values of 67.45% were observed at a forward speed S_2 with A_2 cup size of planter for graded seeds. Similar results also reported in

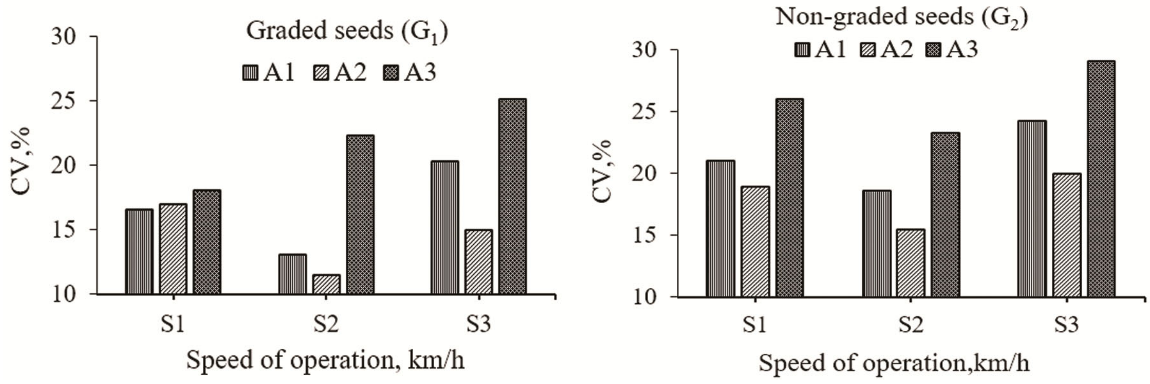

Fig. 14 — Seed spacing for coefficient of variance (CV) of the planter.

previous research studies[23,25,26,27]. The optimal seed metering for ginger planters involves balancing these parameters to ensure uniform seed placement, minimizing missed or multiple seed drops, and maximizing the quality of feed.

3.5 Effect of operational parameters on seed uniformity

The uniformity of rhizomes planting was measured by coefficient of variation in seed spacing. The coefficient of variation of uniformity of rhizome spacing for ginger is given in Fig. 14. The lowest coefficient of variation (CV) value observed was 11.44% for graded seed at forward speed of S_2 (2 km/h) and A_2 cup size. As the speed of operation increased the planter might have get the less time to pick and release seed at a precise interval, leading to no-uniform spacing while increasing the cup size generally allows for multiple seeds to be hold and delivered. This can lead to decreased seed spacing if multiple seeds are dropped too closely together. The low values of coefficient of variation for uniformity of rhizome spacing indicated the accuracy and uniformity of spacing of rhizomes in conformity as reported by researchers[28].

3.6 Field capacity and field efficiency

Figure 15 shows that the average field capacity and efficiency of the ginger planter were observed 0.25 ha/h and 70.63% at a forward speed of 2 km/h while field capacity was 0.32 ha/h and 88.76% at a forward speed of 2.5 km/h (Fig. 15). Field capacity and field efficiency of tractor operated mechanical planter was within the acceptable level as recommended for planters[15]. The labour required for the operation is calculated 8 man-h/ha. Considering one plant per hill and missing hill, the required plant population obtained was higher for ridge planter because more than one seed was planted per hill is 23 percent, to achieve nearly get 100 percent germination. The developed ginger planter placed more than 67% of the seeds within the 20–25 cm spacing at a forward speed of 2 km/h.

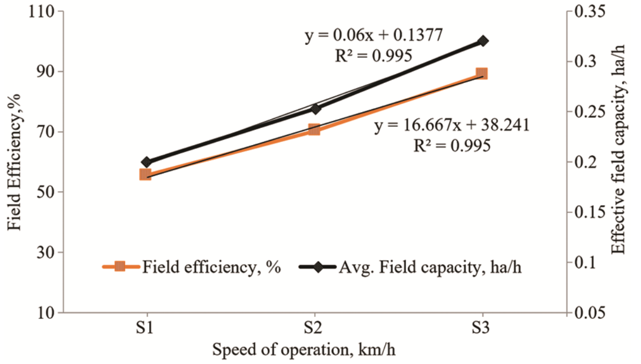

Fig. 15 — Field performance of the developed machine.

3.7 Depth of rhizome placement

The depth of rhizome placement was measured. The average depth of rhizome planting was 8 cm which was within the recommended value of 5 cm to 10 cm for ginger respectively[29]. The field view of machine operation shown in Fig. 16.

3.8 Draft, slip and fuel consumption of planter

The draft force exerted by the tractor to operate the ginger planter was measured, with an average draft of 480 ± 67 kg_f. Minimum and maximum drafts during the operation for smooth operation were found 289 and 564 kg_f, respectively. The tractor ground wheel slip measured was 6% which is within the recommended range of 18% [30]. The planter was operated and fuel consumption for the test area was measured. The fuel consumption obtained was 4.1 L/ ha.

Fig. 16 — Developed ginger planter in field operation.

Table 7 — Comparative performance of planter with conventional planting.

Sl. No.	Parameters	Value
1.	Plant spacing, cm	60×20
2.	Actual Field Capacity (AFC), ha/h	0.25
3.	Field Efficiency (FE), %	70
4.	The initial cost of the machine and Tractor, ₹	45000 & 6,00,000
5.	Fixed cost, ₹/h	129.38
6.	Variable Cost, ₹/h	511.5
7.	Cost of operation of Machine, ₹ / h	642
8.	Cost of operation of Machine, ₹ / ha	3206
9.	Total Cost of planting by Machine including manual cutting, ₹/ ha	5081
10.	Cost of planting by manual method, ₹/ha	8500

3.9 Cost economics

The performance of the planter was compared with manual method of planting. The results are presented in Table 7. The cost of planting per hectare was ₹3206 for the ginger planter less compared to ₹8500 for conventional manual planting. The total cost of planting using the developed machine, if included manual cutting and grading of rhizomes, was ₹5081/h. The effective field capacity of 0.25 ha/ha, higher than the available planters. The total labour hours (50 Man-h/ha) were required for planting with the developed ginger planter, which is 11 times less than the manual planting (250 Man-h/ha).It is imperative from the above results that there is a saving of about 40% in the cost of operation and 76% in labours requirement using the developed planter over conventional planting methods.

4 Conclusion

A tractor-operated ginger planter was developed and evaluated under varying operating conditions. The results showed that increasing the cup size led to a higher percentage of multiple seed placements while reducing the percentage of misses. The highest quality of feed index was observed with cup size A_2 with graded seeds. The planter demonstrated precise planting for ginger rhizomes, with an effective field capacity of 0.25 ha/h at a forward speed of 2 km/h and required only 50 man-h/ha. It also reduced operational costs by 40% and labour requirements by 76% as compared to conventional planting methods. The machine performed better with properly graded seeds, its efficiency has reduced when using non-graded seeds, this is primarily due to the irregular shape, and size of non-graded ginger rhizomes, caused inconsistent picking seeds, leading to increased misses, multiple seed drops, and clogging in the metering system. These non-uniformities of seed hindered the proper functioning of the seed metering system. To enhance its suitability and adaptability for non-graded seed, which are commonly used by farmers' variability further refinements of the planter are necessary.

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