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Research article

Conceptualization and development of a semi-automatic vegetable transplanter prototype for small landholdings

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ABSTRACT

The process of seedling transplantation has significant importance within the realm of mechanical vegetable production in contemporary agriculture. A prototype of a two-row tractor-mounted semi-automatic vegetable seedling transplanter (SVT) was conceptualized and developed for small agricultural holdings. The functional behaviour of the prototype was examined with computer-aided design tools, and the various units of the prototype have been finalized. To develop the prototype, the feeding, metering, transplanting, drive train, and soil compacting/covering unit of the machine were developed and constructed using materials readily accessible locally. The machine has a set row-to-row spacing of 600 mm, and it may alter the plant-to-plant spacing when the machine's forward speed changes. The pace was customized to achieve the required 450 mm plant-to-plant spacing. A 12:1 speed reduction gearbox was used for the proper metering of seedlings. The effect of independent factors, namely tray cell type, feeding mechanism, soil covering/compacting wheel angle, and age of seedling, on the machine's actual field capacity (AFC) was examined. The prototype underwent preliminary field testing to assess the functional viability, and the functioning was satisfactory. The main effect of the feeding mechanism and soil covering/compacting wheel angle on AFC was statistically significant at 5 % for tomato and brinjal whereas their first-order interaction was found statistically significant on AFC for tomatoes. The findings demonstrate that this study's prototype can be marketed or used to further vegetable production studies.

1. Introduction

The hand transplanting of seedlings is the predominant method used for cultivating vegetable crops in India. However, it is important to note that this approach incurs significant costs, requires a substantial investment of time, and demands a significant work force [1]. During periods of high demand, physical labor is insufficient to fulfill the transplanting needs of vegetable plants. In addition to the significant time investment, hand transplantation involves a considerable amount of labor and personal anguish. The manual transplantation procedure, conducted while assuming stooping and crouching positions, is a physically demanding task that is not viable. According to a study, the oxygen consumption during squatting with movement activity and bending posture ranges from 31 to 35 percent and 70 to 80 percent of VO_2 max, respectively [2]. Consequently, there is an increased level of fatigue and a decrease in

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productivity. The economic viability of manual transplanting has been compromised because to the escalating labor expenses seen over the last decade. Therefore, researchers are developing mechanical transplanters to tackle the difficulties linked to hand transplantation. The process of mechanizing transplanting aims to decrease the reliance on human labor in cultivation tasks, while also minimizing damage to seedlings and optimizing efficiency [3]. In industrialized countries, vegetable seedlings were transplanted using a transplanter that operated either entirely automatically or semi-automatically. In fully automated transplanters, seedlings are metered and fed automatically, whereas in semi-automatic transplanters, the metering and feeding processes are performed both mechanically and manually. Both types of transplanters are equally effective in field vegetable production, depending on the operator and the size of the farm [4–6]. Although there are several automated transplanters available, they are costly and need higher power consumption [3,7,8]. Semi-automated transplanters are less expensive compared to fully automatic transplanters. The use of fully automated transplanters is limited to seedlings cultivated in cells or cups, while semi-automatic transplanters are capable of accommodating both bare-root seedlings and plug seedlings [3]. A tomato transplanter with a conical distributor cup had been designed and built [8], operating on a semi-automatic system. Transplants were conveyed by a semi-automatic distributor and thereafter directed via conical bowls into the fall tube, where they were subsequently transported to the furrow created by the furrower. The optimal forward velocity and cultivation altitude were determined to be 2 km h^{-1} and 0.05 m, respectively. The machine was calculated to have a theoretical capacity of 0.008 ha per hour while operating at a forward speed of 2 km per hour in a single cultivation row.

Two kinds of transplanters were developed, constructed, and evaluated [9] to automate seedling operations: the power tiller-operated semi-automatic dibbler vegetable seedling (DVS) transplanter and the furrow opener vegetable seedling (FVS) transplanter. The dibbler and furrow opener, which were the main design elements, have been effectively integrated into the DVS and FVS transplanters, respectively. When the dibbler was pressed into the earth, it creates a hole for seedling transplanting by exerting a downward force on the bigger sprocket via a chain. In contrast, a furrow opener is used as an alternative to a dibbler, which is responsible for creating furrows to accommodate the planting of seedlings. Our research findings indicate that the DVS and FVS transplanters provide the flexibility to modify the distance between rows, with possible ranges of 0.50–0.81 m and 20–0.80 m, respectively. In a similar vein, the spacing between seedlings may be modified within the range of 0.258–0.620 m for DVS transplanters and 0.125 m for FVS transplanters, allowing for any desired distance. It is noteworthy that both categories of transplanters demonstrated accurate seedling placement, with no occurrences of seedling absence seen throughout the laboratory experiment. In comparison to the DVS transplanter, the FVS transplanter exhibited a reduced level of vertical axis inclination during transplantation, hence underscoring its better performance. The DVS transplanters have an average depth of implantation of 0.0325 m, but the FVS transplanter has a broader depth range of 0.02–0.08 m. The results of field studies done at an average forward speed of 1.2 km h^{-1} demonstrated significant field capacity and field efficiency. The DVS transplanters exhibited a field capacity of 0.05 ha h^{-1}, while the FVS transplanters demonstrated a field efficiency of 61.18 %. Moreover, the results obtained from the field trial also indicated that the variables associated with brinjal production and yield contribution exhibited no significant changes, therefore validating the feasibility of using the transplanter in actual applications. In brief, the utilization of a semi-automated mechanical vegetable seedling transplanter presents a multitude of advantages, including decreased manual effort, temporal efficiency, and the capacity to guarantee a fair allocation of seedlings. According to a study conducted by Ref. [10], it was found that Indian vegetable growers have a need for a cost-effective vegetable transplanter in order to address automation gaps in the seeding, planting, and transplanting processes of vegetable crops. As per the preliminary statistics from the [11], 86.2 % of Indian farmers own less than 2 ha of land, but just 47.3 % of arable land. According to the report, there are around 126 million smallholder and marginal farmers, which own the combined 74.4 million hectares of land, are insufficient to generate surpluses that would allow them to support their families financially. This explains Indian farmers' rising anxiety. Others argue that India should recognize its smallholder farms and make them lucrative for sustainable development [12]. In India's Jammu and Kashmir (J&K), 94.78 % are marginal and small farmers, 5.82 % semi-medium and medium, and 0.04 % big holding [13]. J&K grows tomatoes, onions, cabbage, brinjal, chilli, and more produce. Brinjal and tomato are cultivated in 8.1 % and 11.3 % of vegetable agriculture in J&K [14].

The degree and extent of agricultural mechanization in the union territory of Jammu and Kashmir are limited due to factors such as the presence of small and uneven fields, undulating terrain, a scarcity of trained labor, and inadequate facilities for the repair, maintenance, and manufacturing of agricultural equipment. Furthermore, the presence of tiny landholdings, undulating terrain, and terraced irregular form fields, coupled with farmers' limited investment ability, poses significant challenges to the implementation of automation using the existing agricultural equipment available in the market. There is currently a shortage of availability for an efficient semi-automatic transplanter for vegetable seedlings in small to medium-sized vegetable farms in underdeveloped countries. The use of a cost-effective transplanter that operates on the same energy source as a power tiller has the potential to greatly benefit the local vegetable-producing industry [9]. The use of cost-effective technology for transplanting vegetable seedlings may provide advantages compared to conventional culture methods and is now a pressing need in vegetable farming [15,16]. There is a pressing need to create a cost-effective, compact, conveniently transportable, reasonably priced, and highly efficient semi-automatic vegetable transplanter (SVT) for plug seedlings that can be effortlessly handled in mountainous regions and is well-suited for small-scale agriculture. In light of the aforementioned limitations and requirements, the current investigation has been conducted to conceptualize and construct a prototype of a two-row semi-automatic vegetable transplanter (SVT) system tailored for small-scale agricultural practitioners.

2. Materials and methods

Based on an examination of the vegetable crop seedling, a prototype semi-automatic transplanter for plug-type seedlings was designed and developed [17,18]. The computer-aided design software was used to conceptualize a tractor-mounted two-row vegetable transplanter for small-scale farmers. Following the three dimensional modelling process, a prototype of a semi-automatic vegetable transplanter (SVT) for plug-type vegetable seedlings was designed and built using a two dimensional drawing and a bill of materials. The procedure adopted and the material used to conduct this study has been presented under the following sub-heads.

2.1. *Design consideration of the prototype*

The prototype was designed with the machine's usability in view by the small-holding farmers. The machine was designed for small horsepower or category-I tractors (tractor hp between 20 and 45). In addition, tractor-mounted type machines have improved manoeuvrability, which improves field efficiency. These aspects are essential, as the fields are relatively small (0.2–0.4 ha) and are essential for design consideration. In such small plots, trailed-type equipment is bound to have a high turning radius and time, which lowers the field efficiency. The researchers [19] reported that the vegetable transplanter they developed had low field capacity mainly because their machine was trailed, requiring a very high turn time. It was, therefore, decided to develop a small or category I tractor-mounted SVT with a suitable feeding mechanism. The machine should also be able to transplant seedlings from different vegetable crops. As most of the vegetable cultivation area in the Jammu region of the union territory J&K, India is under brinjal and tomato vegetable crop, to meet their seedling transplanting spacing requirement, the machine should transplant seedlings at row to plant spacing of 600 × 450 mm.

2.1.1. *Functional requirements of proposed prototype*

The following were the functional requirements of the proposed prototype kept into consideration during the study.

- The machine should be tractor-mounted and pulled by a tractor 3-point linkage.
- The machine should be capable of transplanting on flat lands by placing the seedlings in the holes made by the machine openers.
- The row spacing, plant spacing, and transplanting depth should be 600, 450, and 30 mm, varying from 25 to 50 mm.
- The feeding mechanism should be such that the seedlings are placed, carried, and safely released in the transplanting unit.
- The transplanting unit should be able to transplant seedlings at proper depth and orientation without significant damage to the seedlings.
- The soil around the transplanted seedlings should be firmly compacted.

2.1.2. *Design requirements of the proposed prototype*

The following were the design requirements of the proposed prototype kept into consideration during the investigation.

- Ingress of the seedlings into the feeding mechanism ought to be effortless.
- The operator's workspace should be designed as per feasibility and comfortability.
- Placing the seedlings in the holes should be smooth and proper and require minimum energy.
- The seedling should be transplanted in the vertical position.
- The transplanter should plant the seedling in a straight row with inter-row variation not exceeding ±20–40 mm.
- The transplanter should have the provisions to adjust the plant spacing within the row by regulating the number of teeth on the spacing sprocket and the number of plant holding pockets around the conveyer chain or disk.
- The transplanter's design should preserve regular planting depth, row spacing, and plant spacing while avoiding harming seedlings and working with various vegetable crops.
- The feeding mechanism must be simple in design and mechanical adjustments.
- It should be simple to transport, dismantle, and reassemble the machine in rural areas.

Therefore, based on the crop selection, plug type selected seedling characteristics, row-to-row and plant-to-plant spacing (600 × 450 mm), and optimum drop height of 400 mm for plug seedlings [20], the prototype was designed on computer aided design software

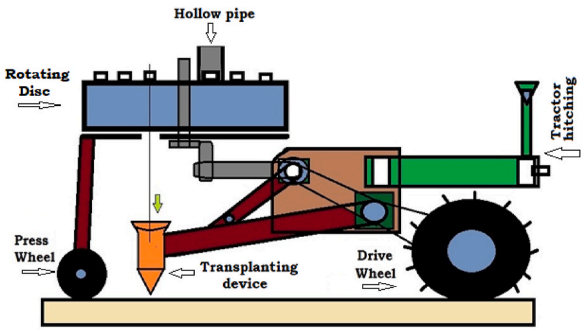


Fig. 1. Conceptual design side view of the prototype.

and its functional behaviour which included functions of feeding and transplanting mechanisms, cranks and linkages were observed. Considering the functional behaviour of the drawing model of the prototype, the different parts of the transplanter were developed and fabricated. The side view of the conceptual design of the prototype is shown in Fig. 1.

2.2. Semi-automatic vegetable transplanter units

Developing the SVT prototype involves designing feeding, metering, transplanting, drive train, and soil compaction unit. Selecting drive wheel, drive sprockets, main and intermediate shafts, speed reduction gearbox, and other components for different assemblies is part of SVT development. The prototype's units are described below.

2.2.1. Seedling feeding unit

The feeding unit includes two mechanical feeding mechanisms, namely a rotating disc and parallel moving pipes, which have spinning and parallel motions concerning the machine's forward motion [4]. These feed plug seedlings to the transplanting unit to accomplish the transplanting operation. A rotating disc-type feeding mechanism was made from two 762 mm circular 14 gauge mild steel (M.S.) plates. An M.S. sheet was welded between the plates at 76 mm. This disc has 12 slots with diameters of 70 mm and lengths of 76 mm to match the wall clock's 12 digits. The 12 M S. circular plates of 100 diameters were fitted and bolted to one side of each of the 12 slots on the disc. A spring connected every circular plate to the pit's opposite side. The rotating disc body supported the horizontal parallel moving pipes feeding method. An 864-mm-long, 10-mm-diameter solid temper rod was linked to the driving shaft's circular plate by a link and arm. The temper rod has six hollow pipes (three per row) connected with clamps that may be released and tightened with the rotating screw. M.S. hollow pipes of 60 and 50 mm diameter and 102 mm length were employed. The selection of the rotating disc was based on its convenient mobility and straightforward design. Nevertheless, the selection of parallel-moving pipes was based on their inherent simplicity.

2.2.2. Metering unit

The metering unit includes a 5-bar crank, and a rocker-type metering mechanism has been fabricated in the current study. The proposed prototype requires workers to feed the seedlings into the feeding mechanism. The seedlings were released at preset locations to fall properly into the planter for smooth planting. Then, the feeding and planting mechanism repeated the above actions. The metering mechanism was fitted on the main beam of the rack through the hinges of two cranks. The mechanical adjustment device can adjust the height and depth of the planting track via a nut and bolt system. The plant spacing can be adjusted by changing the sprocket (fitted on the drive wheel shaft) or by varying the tractor's forward speed. The metering mechanism comprised of a crank and connecting rods [4].

2.2.3. Transplanting unit

The planter for the proposed prototype picked the seedlings from the feeding unit and transplanted them into the soil by punching holes. The planter was a bearing-fitted hopping dibber type, which included a hopper (seedlings picking device), connecting pieces, a dibber mechanism, return springs, a fixed connector, and fitted levers. The dibber planter, having a bearing fitted lever welded from the two sides, was mounted with the seedlings picking device. The bearing lever and hopper were an integral part of the dibber. It opened and closed promptly and performed the functions of punching, picking seedlings, and planting [4].

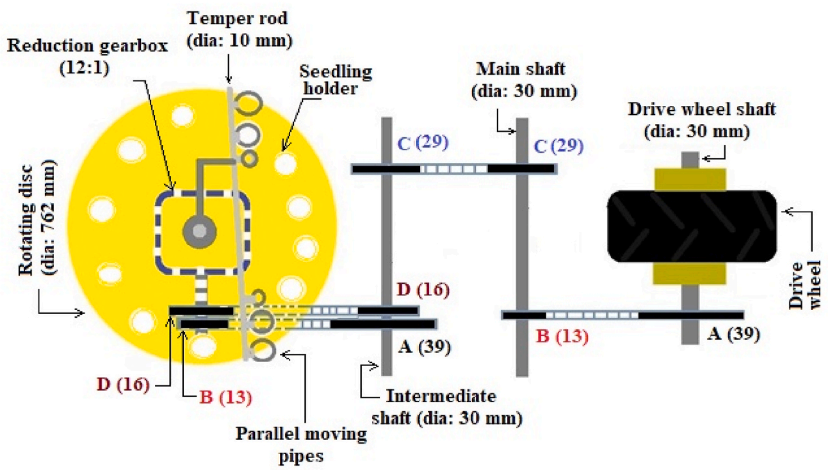


Fig. 2. Top view of the prototype drive system.

2.2.4. *Machine systems drive*

A chain and sprocket, each having 39 (A) and 13 (B) teeth, were used to transfer power to the main shaft from the driving wheel. The intermediate shaft had the same 29-toothed (C) sprocket on one end, driven by another sprocket linked to the opposite end of the main shaft. The power was then transferred from the intermediate shaft to the input shaft of the reduction gearbox using the same 16-tooth (D) sprocket on both shafts in the case of a rotating disc and a 39-tooth (A) sprocket on the intermediate shaft to a 13-tooth (B) sprocket on the gearbox's input shaft in the case of a parallel moving mechanism. Using a gear reduction box, the power was sent to the feeding system after being reduced to a 12:1 ratio. In order to supply seedlings with the correct spacing for the rotating disc and magazine feeding mechanism, the speed ratios of 4:1 and 1.33:1 were maintained. Fig. 2 depicts the whole power path of the drive train system starting at the ground wheel.

2.2.4.1. Drive wheel design. A pneumatic drive/ground wheel with 16 lugs/spikes of dimensions 102 × 15 × 32 mm (L × W × H) on its periphery was fitted in the machine's centre on the front side, and power was supplied to the metering mechanism via the drive wheel. When the machine was lowered entirely during the operation, the drive and four press wheels served as support wheels. A nut and bolt system was in place for adjusting the drive wheel's vertical position (lowering and lifting).

The feeding and planting mechanism was driven through a drive wheel, main shaft, and chain sprocket system. The drive wheel rotated a hub with a 39 teeth sprocket attached to the drive wheel shaft axle, and power was transmitted through the chain to another 13 teeth sprocket on the main shaft having a diameter of 30 mm. The primary function of the drive wheel was to give drive to the seedling feeding and metering mechanism. With the help of Equation (1), and (2), the diameter of the drive wheel (D) and thickness (T) of the wheel rim [21] was calculated as 573.24 and 6.04 mm, respectively:

$$D\ (\mathrm{mm}) = \frac{n \cdot p}{\pi} \tag{1}$$

$$T\ (\mathrm{mm}) = \frac{D}{200} + 3.175 \tag{2}$$

where, n: no. of seedlings dropped in one revolution; p: plant to plant distance, mm.

The diameter and rim width of the drive wheel used in the present study was kept at 521 and 200 mm (including lug height) because of its easy availability in the local market.

2.2.4.2. Drive wheel power requirement. To rotate the drive/ground wheel, the tangential force (F) of 1224.01 kg (11995.30 N) was calculated from Equation (3) [22] on substituting, coefficient of soil cohesion for friable range (C): 0.02, drive wheel width (B): 20.32 cm, length of contact of drive wheel (L): 16.15 cm, weight on drive wheel (G): 192 kg (assuming 60 % of total machine weight + 75 kg human weight), and angle of soil internal friction (θ): 40° (sandy loam soil):

$$F = C \cdot B \cdot L \cdot G \cdot \tan\theta \tag{3}$$

After the determination of force (F), using the standard Equations (4) and (5) the torque (T_r) and power (P) was found to be 3130.77 Nm and 4.52 hp,

$$T_r = F \cdot r \tag{4}$$

$$P\ (kW) = \frac{T_r \cdot speed}{9549} \tag{5}$$

As maximum speed of transplanter (S_m) should be 350 mm s^{-1} [23]. Therefore, by using the standard Equation (6), the maximum speed (rpm) of drive wheel (W_d) was found to be 13.

$$W_d = \frac{S_m}{\pi \cdot D} \tag{6}$$

In the current study, considering 15 % factor of safety (FOS) for drive wheel power requirement, the maximum speed of drive wheel power requirement was calculated as 15 rpm and 7 hp.

2.2.4.3. Main and intermediate shaft. A 30 mm diameter iron solid shaft of length 610 mm was provided on the main body frame of the machine. This central shaft was supported on four flange-type self-aligning bearings mounted on the main body frame. A 13-teeth sprocket was mounted on one end of the main shaft, driven by a 39-teeth sprocket on the ground wheel axle. On the other end of the shaft, 26 teeth sprocket was mounted, transmitting the power to a 521 mm long, 30 mm diameter intermediate solid shaft with 26 teeth sprocket. Two sprockets with 39 and 16 teeth were mounted on the other end of the intermediate shaft. The 16 teeth sprocket was used to give drive to a 16 teeth sprocket mounted on the reduction gearbox input shaft for giving movement to the rotating disc, whereas 39 teeth sprocket gave drive to 13 teeth sprocket mounted on the reduction gearbox input shaft for giving movement to the moving pipes mechanism.

2.2.5. *Power transmission functional components design*

The drive to the main shaft was given from the ground wheel axle. A sprocket of 39 teeth was fitted on the axle of the ground wheel, and a sprocket of 13 teeth was fitted on the one end of the main shaft. The actual machine speed (V_m), rpm of the rotating disc (C_{rpm}) and actual ground wheel rpm (G_{rpm}) was calculated (Table 1) from Equations (7)–(9):

$$V_m = \frac{K \cdot A_g}{60} \quad (7)$$

$$C_{rpm} = \frac{K}{N_c} \quad (8)$$

$$G_{rpm} = \frac{V_m}{\pi \cdot D} \quad (9)$$

2.2.5.1. Drive wheel shaft design. Based on the details, assumption and parameters values given in Table 1, drive wheel shaft has been designed with the help of Equations (10)–(18) as below:

$$G_p = \frac{2 \cdot \pi \cdot G_{rpm} \cdot T_w}{4500} \quad (10)$$

$$C_p = \frac{P_t \bullet S_c}{75} \quad (11)$$

$$S_c = N_t \cdot p \cdot S_r \quad (12)$$

Table 1
Parameters detail used in the design of drive wheel, main and intermediate shaft [24–26].

Parameter	Abbreviation/detail	Value
Seedlings plant to plant distance	A_g	0.45 m
Actual machine speed	V_m	0.28 m s^{-1}
Number of plants fed·min^{-1}	K	37.33
Ground wheel diameter	D	0.521 m
Number of slots on the disc	N_c	12
RPM of the rotating disc	C_{rpm}	3.11
Actual ground wheel rpm	G_{rpm}	10.27
Drive chain	Chain no. 10B, single strand roller chain	Pitch 15.875 mm
Total weight of the machine	M_w	245 kg
Maximum weight on the axle shaft	$0.6M_w$	147 kg
Assumed weight on the axle shaft	F	150 kg
Minimum breaking load	Q'	2265.3 kgf
Width between inner plate	b	11.7 mm
Coefficient of rolling resistance force	C_{rf}	0.2 kg cm^{-2}
Rolling resistance force	F_r=F· C_{rf}	30 kg
Ground wheel torque	$T_w = F_r \cdot (D/2)$	783 kgf-cm
The power transmitted by the ground wheel	G_p	0.112 hp
Number of teeth on sprocket	N_t	39
Chain pitch	p	15.875/1000
Sprocket rpm	S_r	10.27
Chain speed	S_c	6.36 m min^{-1}
Chain pull (kgf)	P_t	76.36 kgf
Horse power transmitted by chain drive	C_p	0.112 hp
Power transmitted by chain on the basis of breaking load	C_{bp}	0.46 hp
Service factor	$Sf_1 = K_1 \cdot K_2 \cdot K_3$	2.34
Load factor	K_1	1.5
Lubrication factor	K_2	1.25
Rating factor	K_3	1.25
Factor of safety (for chain)	FOS	3–5
Factor of safety (for mild steel)	K_m	1.15
Chain load	Q	87.81 kgf
Angle of chain drive with horizontal	θ	18.26°
Actual chain load	Q_v	27.22 kgf
Weight on wheel	W_m	150 kg
Distance between two end points	b	0.38
Main axle shaft bending moment	M_t	1425 kgf-cm
Combined shock and fatigue factor for bending	K_b	1.5
Combined shock and fatigue factor for torsion	K_t	1.0
Equivalent bending moment	M_{be}	2276 kgf-cm
Allowable shear stress	σ_a	600 kgf·cm^{-2}
Ground wheel shaft diameter	d_g	26.50 mm
Diameter of the main shaft	d_m	30.94 mm
Diameter of the intermediate shaft	di	29.10 mm

$$C_{bp} = \frac{Q' \cdot S_c}{4500 \cdot Sf_1 \cdot FOS} \tag{13}$$

It was found that, $C_{bp} > C_p$, hence, selected chain was safe.

$$Q = K_m \cdot P_t \tag{14}$$

$$Q_v = Q \cdot \sin\theta \tag{15}$$

$$M_t = \frac{W_m \cdot b}{4} \tag{16}$$

$$M_{be} = ((M_b \cdot K_b)^2 + (K_t \cdot T_W)^2)^{1/2} \tag{17}$$

$$d_g^3 = (16 \cdot M_{be})/(\pi \cdot \sigma_a) \tag{18}$$

After using Equations (10)–(18), the drive wheel shaft diameter was calculated as 26.5 mm and considering the factor of safety of 1.2 [24] the diameter obtained was 31.8 mm. Therefore, selected ground wheel shaft diameter (d_{gs}) was 30 mm (based on simplicity and uniformity).

2.2.5.2. Main and intermediate shaft design. In case of main shaft, the chain load is transferred at the velocity ratio of 1:3. Therefore, chain load on main shaft was calculated as 81.66 kgf. Using Equations (16)–(18), the main shaft bending moment, equivalent bending moment and diameter was calculated as 1245 kgf-cm, 1310 kgf-cm, and 22.14 mm. Considering the factor of safety of 1.4 the diameter of main shaft was calculated as 30.94 mm. Again, for uniformity and simplicity the diameter of main shaft was selected as 30 mm. In case of intermediate shaft, the chain load transferred at the velocity ratio of 1:1. Therefore, chain load on the intermediate shaft was calculated as 81.66 kgf. Following the same procedure as in the case of the main shaft design, the diameter of the intermediate shaft (d_i) was obtained as 29.10 mm, and the selected diameter of the intermediate shaft was 30 mm.

2.2.5.3. Chain and sprocket arrangement. Sprockets are positive drives that transmit power to the driven shaft without slippage. The belt work cannot be selected due to its sagging under excessive loads, which leads to the loosening of the belt, thereby causing slippage. The sprockets are selected according to the speed ratio and power requirement. There is an intermediate shaft between the main shaft and the reduction gearbox input shaft for transmitting power from the ground wheel to the metering shaft through chains and sprockets. The chain was selected for transmitting motion and power from one shaft to another. The chain's pitch was selected according to the sprocket's power and speed. The number of chain links (N_L) and chain length (L) was calculated [27] from Equations (19) and (20). Table 2 depicts the values of the parameters used and chain length obtained.

$$N_L = \frac{T_1 + T_2}{2} + \frac{2C}{p} + \left(\frac{T_2 - T_1}{2\pi}\right)^2 \frac{p}{C} \tag{19}$$

Table 2
Parameters detail used in the chain and sprocket arrangement.

Parameter	Abbreviation	Value
Chain joining the drive wheel and main shaft		
No. of teeth on driver sprocket	T_1	39
No. of teeth on driven sprocket	T_2	13
Distance between two shafts	C	400
Chain pitch	p	15.875 mm
Chain length	L	1223.49 mm
Chain joining the main and intermediately shaft		
No. of teeth on driver sprocket	T_1	29
No. of teeth on driven sprocket	T_2	29
Distance between two shafts	C	340
Chain pitch	p	15.875 mm
Chain length	L	1140.30 mm
Chain joining the intermediately and gearbox shaft (rotating disc)		
No. of teeth on driver sprocket	T_1	16
No. of teeth on driven sprocket	T_2	16
Distance between two shafts	C	381
Chain pitch	p	15.875 mm
Chain length	L	1016.00 mm
Chain joining the intermediately and gearbox shaft (parallel moving pipes)		
No. of teeth on driver sprocket	T_1	39
No. of teeth on driven sprocket	T_2	13
Distance between two shafts	C	381
Chain pitch	p	12.31 mm
Chain length	L	1088.82 mm

$$L = N_L \cdot p \quad (20)$$

2.2.5.4. Design of speed reduction gearbox. A pair of worm gears is specified in Fig. 3 and designated by four quantities in the following manner,

$z_1/z_2/q/m$

where, z_1: number of starts on worm; z_2 = number of teeth on worm wheel; q: diametral quotient; m = axial module (mm)

In the current study, gearbox needed to be designed for speed ratio (*i*) of 12:1, the recommended [27,28] number of starts (z_1) on worm 02 (double start).

Now, as speed ratio is given by $i = \frac{z_2}{z_1} = \frac{12}{1}$.

$$Z_2 = 2 \times 12 = 24$$

In order to account for worm rigidity in bending, greater values of q was used for lower values of m [27]. The preferred [28] values of q are 8, 10, 12.5, 16, 20 and 25. Therefore, m = 2 and q = 16 has been selected.

Worm pitch circle diameter (d_1), axial pitch (p_x) of worm, lead (l) of worm and worm wheel pitch circle diameter (d_2) was calculated from Equations (21)–(24).

$$d_1\ (mm) = q \cdot m \quad (21)$$

$$p_x\ (mm) = \pi \cdot m \quad (22)$$

$$l\ (mm) = p_x \cdot z_1 \quad (23)$$

$$d_2\ (mm) = m \cdot z_2 \quad (24)$$

The lead (γ) and helix (Ψ) angle (degree) of worm, centre-to-centre distance (a) between worm and worm wheel and the length (L_w) of worm was calculated from Equations (25)–(28).

$$\tan\gamma = \frac{l}{\pi d_1} \text{ or } \tan\gamma = \frac{z_1}{q} \quad (25)$$

$$\Psi = \pi/2 - \gamma \quad (26)$$

$$a = \frac{1}{2}(d_1 + d_2) \text{ or } a = \frac{1}{2} m (q + z_2) \quad (27)$$

$$L_w\ (mm) = 4.5 \cdot p_x + 0.02 \cdot z_1 . p_x \text{ or } L_w\ (mm) = 14\ m + 0.06 \cdot z_1 . m \quad (28)$$

From the recommended values of $z_1/z_2/q/m$ (2/24/16/2) in standard design procedure [27,28] for desired transmission ratio (12:1) the following parameters were obtained:

$d_1 = 32.0$ mm; $d_2 = 48.0$ mm; $p_x = 6.28$ mm; $l = 12.56$ mm; $\gamma = 7.13^\circ$; $\Psi = 82.87^o$; a = 40 mm; $L_w = 28.51$ mm; pressure angle (ϕ) = 14.5^o

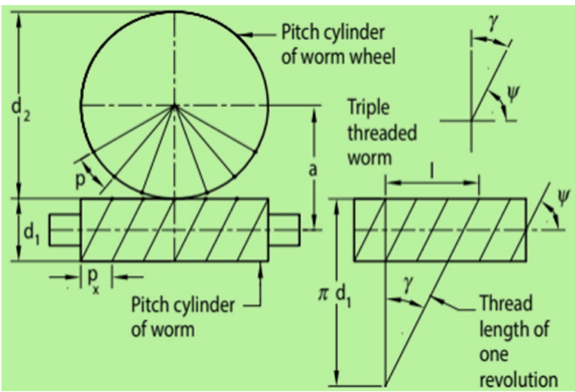


Fig. 3. Worm Gear Terminology [28].

2.2.6. Soil compacting devices

The current study used two pairs of rolling-type press wheels made of nylon material, each with a diameter and width of 203 and 50 mm, respectively. Each wheel was individually joined with a hollow square vertical pipe through a nut and bolt system with the help of the U-shaped clamp. Clamps used to attach each press wheel to the machine body frame consisted of two hollow square pipes of size 51 × 51 mm, which were welded together. Each set of wheels was fixed with a horizontally placed iron pipe of a size 51 × 51 mm of machine frame with the help of a clamp system. Each pair wheel was used for each row. The wheels can be tilted at any angle from the direction of motion by adjusting the nut and bolt system. Each wheel has two sets of roller bearings of size 12 mm each for easy rotation. These press wheels were mounted to be tilted at any angle from the vertical. These press wheels were also used as transport wheels with a zero-degree tilt with the vertical. An iron flat step of 60 mm width was welded on each press wheel clamp body to remove excess soil (scouring) attached to the wheel for smooth functioning.

2.3. Working principle of the prototype

Traction operations for the plug seedling transplanting machine were handled by a tractor. During the operation, the transplanter machine drove smoothly, seedlings catching or picking up from the feeding mechanism and placing them successively into the seedling transferring mechanism. The seedling feeding devices are rotated or moving with the seedling. When it rotated or moved above the guide hole, the spring diaphragm opened automatically to release the seedling in the case of a rotating disc feeding mechanism and directly dropped into the planting device in the case of the parallel moving pipes feeding mechanism. Then, under the spring stress, it closed and held the next seedling. Through the guided openings, the released seedlings were precisely put above the spatial position of the planter. At this time, the 5-bar type hopping dibber mechanism moved to its highest position. Then, the plug seedlings were accessed. When the hopping dibber mechanism carried the seedling to the lowest position, the bearing lever was compressed through the M.S. door, and the hopping dibber was opened to release the seedling for planting. The planting operation was then completed by the falling soil and the soil covering mechanism. When the planting mechanism moved away from the seedlings, the hopping dibber was closed and entered the next working cycle to achieve transplanting. The working flow diagram of the developed prototype is shown in Fig. 5.

2.4. Prototype development

2.4.1. Material selection

The prototype was fabricated with locally available material. The mild steel (M.S.) was used to fabricate every part of the transplanter except the reduction gearbox, which was made of cast iron. The square section M.S. pipe and sheet of different gauges were used per the fabrication requirements. The nylock nuts of different sizes were used to fit different transplanter parts properly. The developed SVT was weighed as 245 kg.

2.4.2. Frame and the hitch system

The hitch system was designed with the standards for lower and top links of the category-I tractors. The top of the frame and hitch system with various dimensions are shown in Fig. 6. The frame which supported all components of the transplanter machine consisted of two rectangle iron plates rounded from one corner, square hollow pipe, iron strips of different sizes on which feeding system, metering system, press wheel, ground wheel, transplanting unit, three-point hitching system, seating attachment were assembled. The fabricated view is shown in Fig. 7.

2.4.3. Three-point hitch system

A standard hitching arrangement with standard dimensions was developed, keeping the category-I tractor three-point linkage system in view so that the tractor's three-point hitch system could be easily attached to the developed machine. The distance between the two lower links was kept at 660 mm, and the vertical distance between the centre point of the lower and top link hole centre was 483 mm. The pin with a diameter of 19 mm was attached to the forwarded clamp, which had a hole of 20 mm at both ends of the lower link with a nut and bolt system. The back end diameter of the nut and bolt system was 22 mm. Two settings, one at 279 mm and another at 330 mm, were made to keep the distance lower from the ground surface. The three-point hitching system was joined with a machine from two places. The hitching system was welded from the lower link side to the main plate of the machine body and was joined with the machine frame by joining with a 51 × 51 mm pipe having a length of 381 mm, with a nut bolt system from 203 mm below the top link hook. The pipe was welded with the machine body frame. Two clamps extending forward about 64 mm at the upper hook had a hole of diameter 20 mm for joining the top link of the tractor, and the space between the clamps was 55 mm. The whole weight of the machine was supported on these links.

2.4.4. Gearbox

The gearbox consisted of worm gears made up of a worm and a gear (also known as a worm wheel), with non-parallel, non-intersecting shafts oriented 90° to each other. The worm is similar to a screw with a V-type thread, and the gear is similar to a spur gear. Typically, the worm is the driving component, with the worm's thread advancing the teeth of the gear. The worm wheel's teeth encircle the worm's threads and provide line contact between the mating parts. Worm and worm wheels are commonly used for high-speed reduction in a small space. The input and output shafts of the gearbox were 19 and 23 mm in diameter and 40 mm in length, respectively. To provide a 12:1 speed reduction, the two starter worms (attached to the input shaft) meshed with 24-teeth worm wheel gear (attached to the output shaft) at 90^o. The worm and the worm gear were made of BHN (Brinell Hardness Number) 250 case-hardened steel and phosphor bronze, respectively. The reduction gearbox was kept lubricated by filling it with C-oil. The gearbox was fabricated (Fig. 4) from a local manufacturer.

2.4.5. *Plug seedling holding trays and seating attachment*

Seedling holding trays were based on the dimensions of the nursery seedling tray. In this study, two seedling trays were fabricated with mild steel sheet having 1.6 mm thickness with size (L × W × H) of 559 × 356 × 25 mm, respectively, and mounted on the mainframe of the transplanter. Each tray weighed 2.2 kg and was made perforated with several holes of size 10 mm and had cut off 51 × 51 mm at one of the sides of the tray for easy placing and picking of the seedling tray from the tray. One nursery seedling tray can be placed on each of the trays.

The seating attachment for the operator to fill the pit of the rotating disc mechanism and hollow pipe of parallel motion pipes with the desired vegetable seedlings was mounted at the front of the machine. One locally available plastic seat with a width of 305 mm, a backrest height of 330 mm, and a length of 305 mm was attached to the mainframe by attaching a hollow pipe with a length of 241 mm and a diameter of 51 mm (attached to the seat bottom with the help of a nut bot system) to accommodate one person, for feeding seedlings in feeding mechanisms. The operator assumed a position in the forefront, oriented in opposition to the machine's forward movement.

2.4.6. *Main body frame and bearings*

The main body frame of the developed prototype comprised two mild steel rectangular shapes (rounded from one corner) plates weighing 22 kg, each having 508 × 330 × 16 mm dimensions. These plates were placed at a 356 mm distance apart at the machine's centre. It supported every component attached to it, such as primary and intermediate shafts, cranks, adjustable pipe frame, plates joining the drive wheel, pipes joining the three-point linkage, chain, and sprocket system. These plates have two holes with a diameter of 51 mm, one at the side of the rounded corners and the other at the opposite corner. The primary and intermediate shafts were mounted on these plates through these holes with the help of flange-type bearings.

Different types of bearings were used during the prototype production process to ensure the efficient operation of the machine elements. Flange-type square-shaped ball bearings were used at the junction of the main body frame and the primary and intermediate shafts. Flange-mounted bearings were employed when the shaft axis was perpendicular to the bearing mounting surface. They have a sealed bearing in flanged housing that is preassembled. Depending on the style, the housing has a precision ground surface perpendicular to the bearing axis and two, three, or four mounting holes. Unlike typical rotary bearings that must be press-fit into a housing, the bearing may be unbolted and removed, making bearing replacement more accessible and faster. The arm connecting the temper rod has been provided with cylindrical form roller bearings. The ball bearings were used in the bearings attached to the lever of the hopping dibber planting apparatus. A *ball bearing* is a rolling-element bearing that uses balls to separate the bearings' moving parts, the inner and outer portions. A ball bearing's job is to reduce rotational friction while supporting radial and axial stresses.

The detailed view of developed prototype components is shown in Fig. 8, and the view of the prototype mounted on the tractor is shown in Fig. 9. The specifications of the developed prototype are given in Table 3.

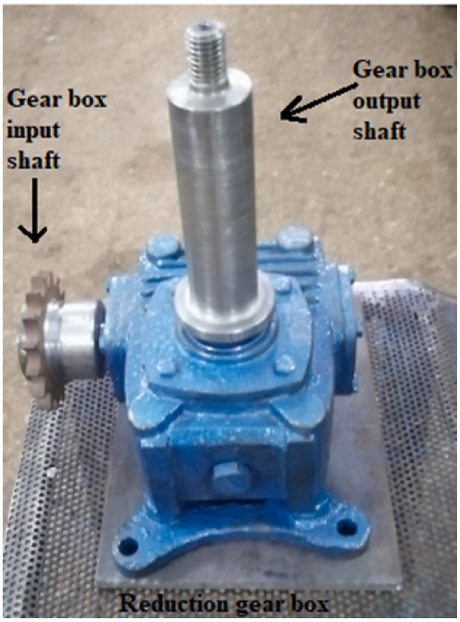


Fig. 4. Fabricated speed reduction gearbox.

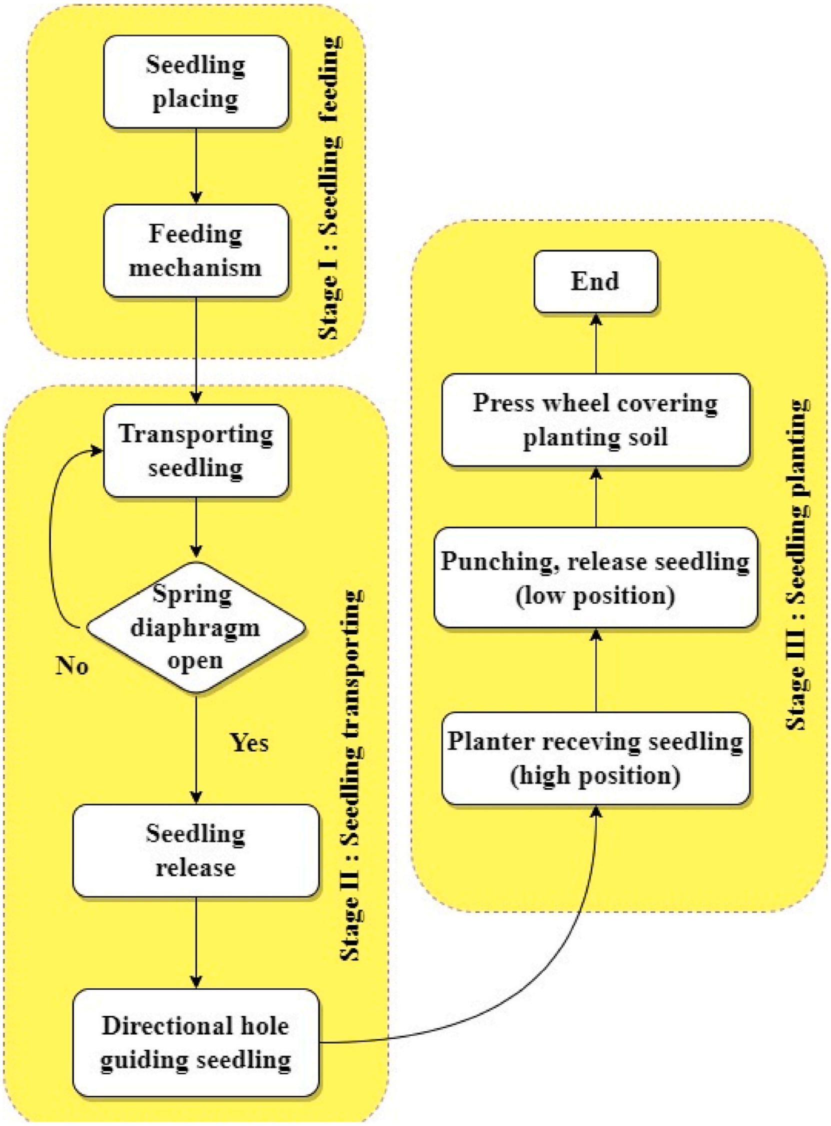


Fig. 5. Working principle of the developed prototype.

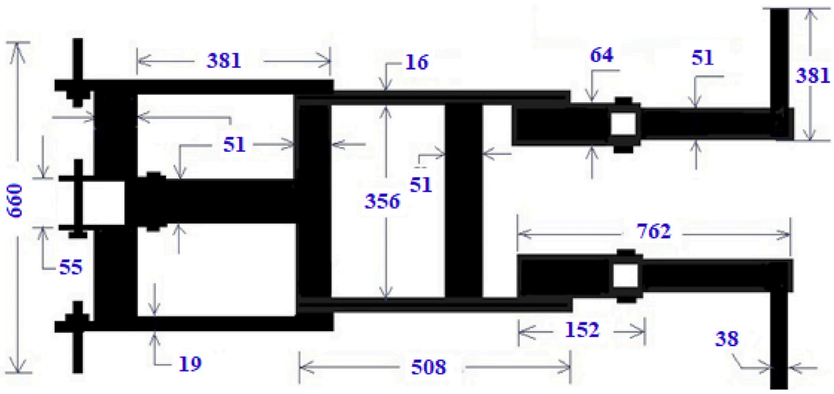


Fig. 6. Dimensional top view of the frame and the hitch system (All dimensions are in mm).

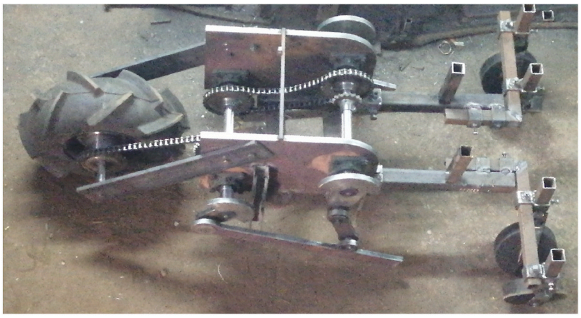


Fig. 7. Fabricated view of prototype frame.

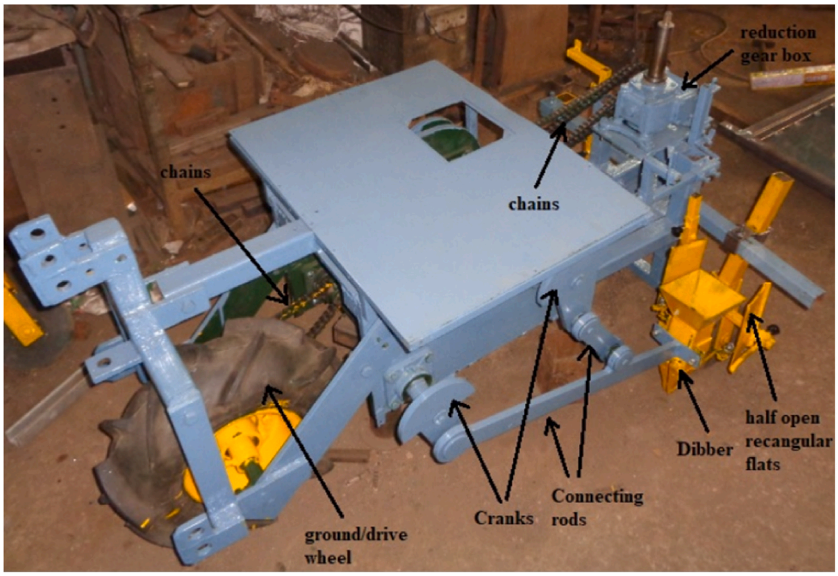


Fig. 8. Detailing of the developed prototype.

Fig. 9. Developed prototype mounted on small horse power tractor.

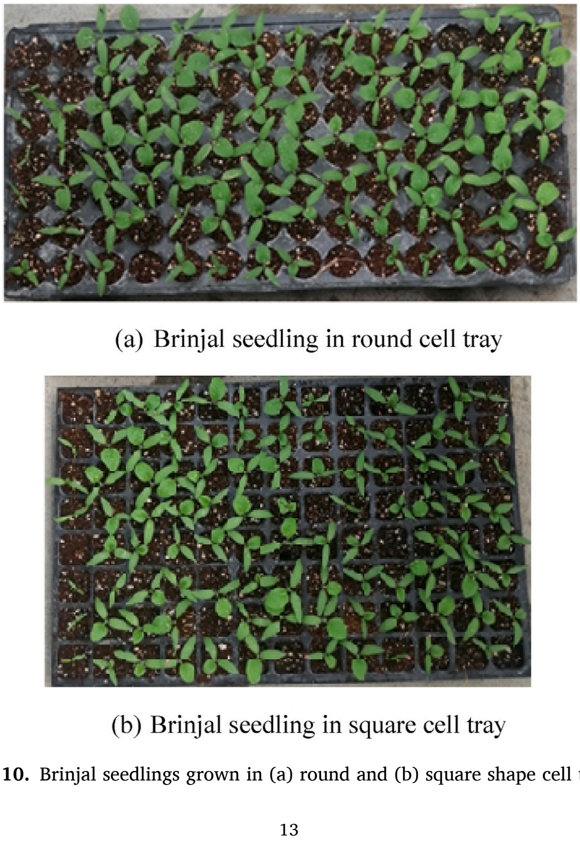
2.5. Field testing

The developed prototype was tested in the field to observe the effect of selected independent factors, such as seedling tray cell shape, feeding mechanisms, soil covering device angle, and seedling age, on the machine's actual field capacity (AFC) for tomato

Table 3
Specifications of the developed prototype.

Parameters	Specifications
Type of Machine	Semi-automatic & mounted type
Power Source	Tractor
Machine Weight (kg)	245
Length (mm), Width (mm), Height (mm)	1400, 1020, 1010
Number of Rows	02
Number of Mechanical Feeding Mechanism	02
Number of Press Wheel	04
Press Wheel Diameter (mm)	203
Press Wheel Width (mm)	50
Number of Drive Wheel	01
Drive Wheel Width and Diameter (mm)	209 and 508

(*Solanum lycopersicum* L.) and brinjal (*Solanum melongena* L.) (Fig. 10) crops. Scheduling field activities, power units, manpower, and estimating machine running costs all depend on measurements or estimations of machine capacity [29]. The AFC (ha·h^{-1}) defined by Ref. [30] is the machine's real average rate of coverage based on the total field time. It is impossible to operate the machines at their rate breadth of action continually, so their actual capacity is far lower than their theoretical capacity [31]. Two plug trays (98 and 104; TC_1: square and *TC2*: round) with varying cell counts and shapes were chosen from the local market for the current study. The way the seedling trays are handled affects how long they last. The design of seedling trays ensures that a sapling receives the proper quantity of moisture and pre-calculated growth medium [32]. Every cavity on the trays has pre-punched holes to ensure adequate drainage of surplus water and correct spacing. Hand feeding is still a common practice for feeding transplanting machines nowadays [33]. Therefore, three systems—rotating disc (FM_1), parallel moving pipes (FM_2), and straight manual feeding (FM_3)—were selected to feed the seedling to the transplanting apparatus. FM_1 retained seedlings on a disc with multiple slots. Vertical pipelines carried vegetable seeds horizontally to the planter in FM_2. FM_3 required hand seedling placement in the planter. As to Ref. [34], transplanting seedlings by machine is considered appropriate if they are squeezed and compacted in a manner that prevents them from rooting out of the soil. The press wheel pressure may be changed using the press wheel adjustment [14]. In a study conducted by Ref. [35], it was discovered that seedling transplanting had superior results when the tilt angle of the soil-covering wheel ranged from 5 to 15°. Therefore, in order to conduct the present studies, three degrees of wheel tilt angle for soil covering were chosen: AN_1 at 5°, AN_2 at 10°, and AN_3 at 15°. To ensure that plants grow and develop to the best of their ability in a particular habitat, seedlings must be transplanted at the appropriate age. Seedlings for the chosen crops should be transplanted at four to five weeks [36,37]. To study seedling age variance, two additional



(a) Brinjal seedling in round cell tray

(b) Brinjal seedling in square cell tray

Fig. 10. Brinjal seedlings grown in (a) round and (b) square shape cell tray.

seedling ages (one week before and one week after the permitted age) were chosen on top of the usual transplanting age. Three 25 (*SA_1*), 32 (*SA_2*), and 40 (*SA_3*)-day-old seedlings were used to test the prototype's response to different seedling ages. For each crop, a field belonging to a farmer was chosen for the experiment. The area was split into smaller sections of 6 0.6 m to facilitate the individual transplantation of tomato and brinjal seedlings. The whole field was prepped using standard equipment before the transplanting process, and the prescribed dosage of urea and phosphate was administered. Enough headland was given to facilitate the assembly of the machine according to the required mechanism, as well as to let the subjects get used to operating and feeding the machine. For the chosen crop to be transplanted, the machine was configured with a row-to-row spacing of 600 mm and a plant-to-plant spacing of 450 mm (±50 mm). The traditional method of transplanting included the laborious removal of seedlings from nursery trays and their subsequent placement on a meticulously prepared field. To do the mechanical transplanting, the tractor's throttle lever was adjusted to the appropriate position, and the first low gear was activated to provide the necessary forward speed for the research, ensuring accurate planting operation and consistent spacing between plants.

2.6. Statistical analysis

The data on the machine's actual field capacity for tomato and brinjal crops were statistically analyzed using a factorial randomized block design. Each level and factor were matched together ("crossed") in factorial analysis of variance, making it easier to understand how the levels and factors interact. For the analysis of variance and comparison of the means at a 5 % level of significance, the statistical software statistical package for the social sciences (version 26) was utilized.

3. Result and discussion

The prototype was initially tested in the farmer's field to observe its workability. The prototype workability in the field was found satisfactory. The respective mechanisms' dropping and catching of seedlings were appropriate, and the desired plant-to-plant distance of 450 mm (±50 mm) was achieved with the tractor I^{st} low gear set. The vibrations issue loosening of the nut and bolt system and jamming of any moveable part were observed and resolved.

The effect of the seedling tray cell type (TC_1: square cell, TC_2: round cell), feeding mechanism (FM_1: rotating disc, FM_2: parallel moving pipes, FM_3: direct manual fed), soil covering/compacting wheel angle (AN_1: 5°, AN_2: 10°, AN_3: 15°) and age of seedling (SA_1: 25 days, SA_2: 32 days, SA_3: 40 days) on the developed machine AFC for tomato and brinjal are presented in Table 4 and discussed as below.

3.1. Effect of selected factors on machine AFC for tomato

The ANOVA and factor means of the AFC for tomatoes are depicted in Table 5. The factors mean value of AFC of tomato crop varied from 0.0461 to 0.0488 ha h^{-1} among all the treatment combinations, and the differences were statistically non-significant at a 5 % significance level. The factors mean of AFC was statistically at par for tray cell type and age of seedling and varied between 0.0474 to 0.0475 and 0.0473–0.0477 ha h^{-1}. The first-order interaction (Fig. 11) of the feeding mechanism and soil covering/compacting wheel angle (FM × AN) was statistically significant on machine AFC at a 5 % significance level. The main effect (Figs. 12 and 13) of the mechanism and wheel angle on machine AFC was also statistically significant at a 5 % significance level. In the case of mechanisms, the

Table 4
Effect of independent parameters on machine actual field capacity (AFC) for tomato and brinjal.

TC	FM	AN	AFC (ha·h^{-1})					
			Tomato			Brinjal		
			SA_1	SA_2	SA_3	SA_1	SA_2	SA_3
TC_1	FM_1	AN_1	0.0482	0.0488	0.0493	0.0464	0.0454	0.0472
		AN_2	0.0481	0.0486	0.0487	0.0454	0.0433	0.0436
		AN_3	0.0480	0.0475	0.0479	0.0404	0.0430	0.0420
	FM_2	AN_1	0.0477	0.0481	0.0468	0.0466	0.0464	0.0428
		AN_2	0.0462	0.0461	0.0462	0.0413	0.0458	0.0415
		AN_3	0.0459	0.0455	0.0450	0.0409	0.0419	0.0415
	FM_3	AN_1	0.0508	0.0504	0.0499	0.0440	0.0441	0.0466
		AN_2	0.0482	0.0494	0.0477	0.0428	0.0427	0.0429
		AN_3	0.0448	0.0444	0.0445	0.0418	0.0423	0.0418
TC_2	FM_1	AN_1	0.0489	0.0498	0.0483	0.0469	0.0484	0.0461
		AN_2	0.0475	0.0483	0.0479	0.0425	0.0452	0.0433
		AN_3	0.0475	0.0468	0.0474	0.0419	0.0418	0.0432
	FM_2	AN_1	0.0466	0.0475	0.0486	0.0435	0.0458	0.0432
		AN_2	0.0463	0.0464	0.0466	0.0421	0.0436	0.042
		AN_3	0.0462	0.0464	0.0465	0.0411	0.0404	0.0409
	FM_3	AN_1	0.0504	0.0499	0.0495	0.0439	0.0475	0.0444
		AN_2	0.0472	0.0491	0.0468	0.0426	0.0428	0.0424
		AN_3	0.0458	0.0457	0.0450	0.0424	0.0407	0.0423

Table 5
ANOVA for tomato and brinjal crop.

Crop	Tray Cell (TC)		Feeding Mechanism (FM)			Soil Covering Wheel Angle (AN)			Age of Seedling (SA)		
	TC_1	TC_2	FM_1	FM_2	FM_3	AN_1	AN_2	AN_3	SA_1	SA_2	SA_3
Tomato	0.0474	0.0475	0.0482	0.0466	0.0477	0.0488	0.0475	0.0461	0.0474	0.0477	0.0473
Brinjal	0.0435	0.0434	0.0442	0.0429	0.0432	0.0455	0.0431	0.0417	0.0431	0.0440	0.0432

Source	Tomato p-value	S/NS	Brinjal p-value	S/NS
TC	0.962	NS	0.706	NS
FM	0.000	S	0.003	S
AN	0.000	S	0.000	S
SA	0.658	NS	0.086	NS
TC × FM	0.668	NS	0.476	NS
TC × AN	0.640	NS	0.924	NS
TC × SA	0.905	NS	0.841	NS
FM × AN	0.001	S	0.613	NS
FM × SA	0.847	NS	0.299	NS
AN × SA	0.872	NS	0.545	NS
TC × FM × AN	0.788	NS	0.877	NS
FM × AN × SA	0.978	NS	0.550	NS
TC × AN × SA	0.999	NS	0.082	NS
TC × FM × SA	0.832	NS	0.531	NS
TC × FM × AN × SA	0.994	NS	0.498	NS

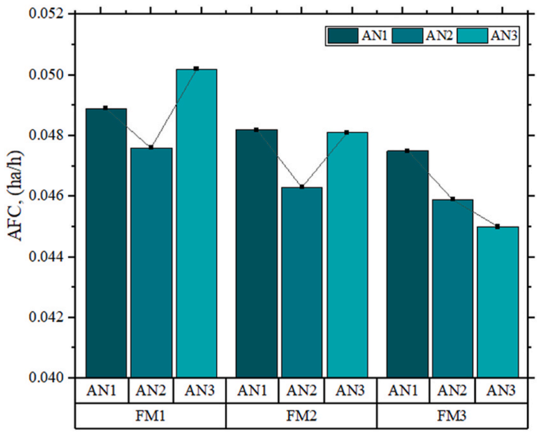


Fig. 11. Effect of feeding mechanism and soil covering wheel angle on machine actual field capacity for tomato.

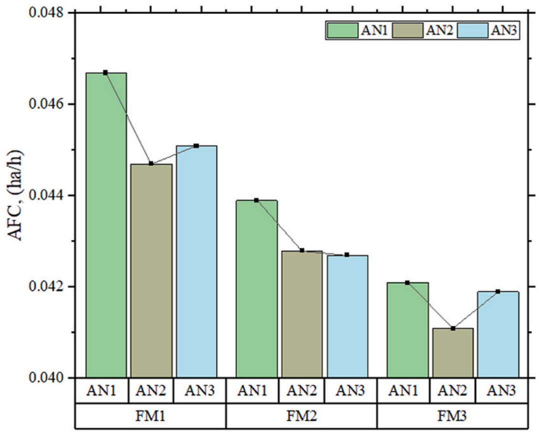


Fig. 12. Effect of feeding mechanism and soil covering wheel angle on machine actual field capacity for brinjal.

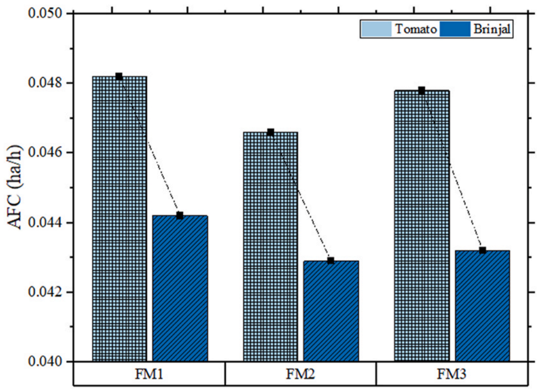


Fig. 13. Effect of feeding mechanism on machine actual field capacity for tomato and brinjal.

factors mean of machine AFC varied from 0.0466 to 0.0482 ha h^{-1} and was maximum for feeding mechanism FM_1 and minimum for the FM_2, whereas, in the case of soil covering/compacting wheel angle, the factors mean of machine AFC varied from 0.0461 to 0.0488 ha h^{-1} and was maximum and minimum for soil covering/compacting wheel angle AN_1 and AN_3 respectively. The interaction among all selected independent parameters was statistically insignificant at a 5 % significance level. The maximum AFC was achieved with the treatment combination of $TC_1FM_3AN_1SA_1$ for tomato crops.

3.2. Effect of selected factors on machine AFC for brinjal

The ANOVA and factor mean of the machine AFC for the brinjal crop are depicted in Table 5. The mean value of the machine AFC of the brinjal crop varied from 0.0417 to 0.0455 ha h^{-1} among all the treatments, and the differences were statistically non-significant at a 5 % significance level. The machine AFC was statistically at par for tray cell type and age of seedling and varied between 0.0434 to 0.0435 and 0.0431–0.0440 ha h^{-1}. The first-order interaction of the feeding mechanism and soil covering/compacting wheel angle (FM $\times$ AN) was statistically non-significant on machine AFC (Fig. 12) at a 5 % significance level. The main effect of the feeding mechanism (FM) and soil covering (AN) on machine AFC was statistically significant (Figs. 13 and 14). In the case of the mechanism, AFC varied from 0.0429 to 0.0442 ha h^{-1} and was maximum for feeding mechanism FM_1 and minimum for feeding mechanism FM_2. Whereas in the case of wheel angle, the machine AFC varied from 0.0417 to 0.0455 ha h^{-1} and was maximum for angle AN_1 and minimum for angle AN_3. The interaction among various independent variables, such as tray cell type, feeding mechanism, soil covering/compacting wheel angle, and seedling age, was statistically non-significant at a 5 % significance level. The maximum AFC was achieved with the treatment combination of $TC_2FM_1AN_1SA_2$ for brinjal crops.

The results revealed that in the case of the tomato crop, the machine AFC was highest for AN_1 (5-degree) soil covering wheel angle. This could be because the machine motion was not obstructed at a lesser wheel angle and acted as proper vertical wheel tires, whereas as the press wheel angle increased, machine movement became more difficult. The actual field capacity was higher in the feeding mechanism FM_3, i.e., the direct manual fed method. This could be due to a mechanical feeding system that needs to be adjusted occasionally during machine movement, reducing the actual field capacity for mechanisms FM_2 and FM_3. For the brinjal crop, the same reason may be stated for the maximum actual field capacity for AN_1 (5-degree) tilt angle as compared to 10 and 15-degree tilt angle and more machine actual field capacity in the case of FM_3, as in the case of transplanting tomato seedling.

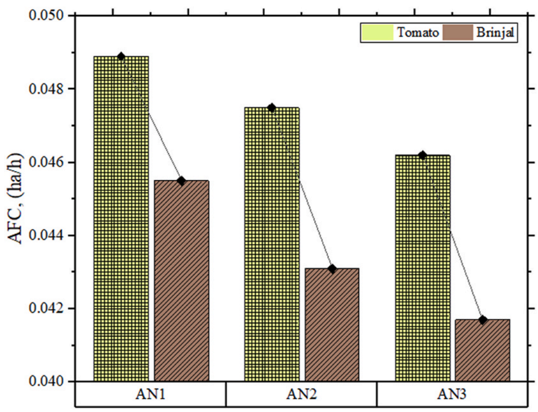


Fig. 14. Effect of soil covering wheel angle on machine actual field capacity for tomato and brinjal.

The traditional method of vegetable transplanting involves manually holding around 100 seedlings in one hand while using the other to separate and place the seedlings into the soil after creating a hole with a tool. Subsequently, the earth is compacted around the roots by applying pressure with the fingers [5]. Upon comparison, it was discovered that the highest field capacity achieved by the produced prototype for tomato and brinjal was 0.0488 and 0.0455 ha h^{-1}, respectively, while the maximum field capacity achieved by the conventional vegetable seedling transplanting technique (manual) was 0.0050 ha h^{-1}. According to Ref. [38], the actual field capacity for tomato and chili was found to be 0.0057 and 0.0029 ha h^{-1}, respectively, during the evaluation of manual vegetable transplanters [39]. reported effective field capacity of 0.018 ha h^{-1} for 3-jaw manual vegetable transplanter [14]. reported the field capacity of 0.05 ha h^{-1} for the power tiller-operated semi-automatic dibbler and the furrow opener vegetable seedling transplanter. Using a power tiller-operated vegetable transplanter [3] discovered that, the effective field capacities for transplanting cabbage, chili, tomato, knolkhol, and brinjal were 0.057, 0.058, 0.073, 0.046, and 0.074 ha h^{-1}. According to Ref. [40], a walk-behind-type hand tractor could transplant tomatoes and chili peppers with a field capacity of 0.045 ha h^{-1}. The effective field capacity of 0.093 ha h^{-1} for tractor mounted automated vegetable transplanter was reported by Ref. [41]. Consequently, although some of the present study's findings are comparable to those of other researchers, others are much higher or lower. In addition, the designed prototype is lightweight (in comparison to existing tractor mounted transplanters), small (simple to portage), and capable of transplanting two rows at once. According to the findings, the prototype created for this study has the potential to be commercialized or to aid future investigations aimed at improving and expanding vegetable production in general.

3.3. Future research scope

The created prototype may be improved in the future by the following projects to make it more reliable and field-worthy.

- To add more rows to the machine in order to expand its field capacity.
- When transplanting seedlings of different crops, provisions for adjusting the gear ratio and row-to-row spacing may be included.
- To enable the transplant to operate on its own, an appropriate engine may be included as a component of the device.
- It may be possible to do field testing in various settings, such as mulching, replanting at the bed, etc.

4. Conclusions

The transplantation of plug seedlings has significant importance in the production of vegetable crops. The present study involved the design and development of a prototype for a semi-automatic vegetable seedling transplanter specifically for plug-type vegetable seedlings. The design was based on the planting geometry and relevant biometric engineering characteristics, taking into consideration the requirements of small landholdings. All the necessary components were assembled to meet these requirements. The compound drawings were created and built using SolidWorks computer-aided design software before fabrication to ensure correctness in the manufacturing process. The prototype was produced by constructing the feeding, metering, transplanting, driving train, and soil compacting/covering unit of the machine using locally available resources. The row-to-row spacing of the prototype was set at a constant value of 600 mm, and it has the potential to impact the spacing between plants when there are variations in the forward speed of the machine. The speed was adjusted to get the desired plant-to-plant spacing of 450 mm. The prototype was subjected to first field testing to evaluate its functional feasibility, and the performance was deemed adequate.

An investigation was conducted to analyze the impact of tray cell type, feeding mechanism, soil covering wheel angle, and seedling age on the machine's actual field capacity. Regarding the tomato crop, the average machine actual field capacity ranged from 0.0466 to 0.0482 ha h^{-1}. The highest value was observed for the rotating disk, while the lowest value was observed for the parallel moving pipes. Similarly, for the soil covering/compacting wheel angle, the average machine actual field capacity ranged from 0.0461 to 0.0488 ha h^{-1}, with the highest and lowest values observed for 5° and 15° respectively. Conversely, in the brinjal scenario, the machine's actual field capacity ranged from 0.0429 to 0.0442 ha h^{-1}. The highest actual field capacity was seen for the spinning disk, while the lowest was observed for the parallel moving pipes. In the context of wheel angle, the actual field capacity of the machine exhibited a range of 0.0417–0.0455 ha h^{-1}, with the highest value seen at an angle of 5° and the lowest value observed at an angle of 15°. The feeding mechanism and soil covering/compacting angle had a statistically significant impact on the actual field capacity of the machine for tomato and brinjal, with a significance level of 5 %. However, their first order interaction had a statistically significant effect on the machine's actual field capacity for tomatoes. The treatment combination of $TC_1FM_3AN_1SA_1$ and $TC_2FM_1AN_1SA_2$ resulted in the attainment of the highest real field capacity for tomato and brinjal crops, respectively. The prototype created for this study has the capacity to be commercialized or to facilitate more research aimed at improving and expanding vegetable production in a broader sense, as shown by the results.

Ethical approval

Not applicable.

Consent to participate

Not applicable.

Consent to publish

Not applicable.

Availability of data and materials

Data will be made available on request.
Compliance with ethical standards.

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CRediT authorship contribution statement

Ankit Sharma: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Sanjay Khar:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.
The declaration of Interest is NONE.

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References

[1] V. Periasamy, Kavithaet Duraisamy, Development of a picking and dropping mechanism for protray grown vegetable seedlings, Journal of Applied and Natural Science 13 (SI) (2021) 47–54, https://doi.org/10.31018/jans.v13iSI.2776.
[2] É. Grandjean, Fitting the Task to the Man: a Textbook of Occupational Ergonomics, fourth ed., Taylor and Francis, London, New York, 1988.
[3] M. Mahapatra, P.S. Chattopadhyay, Design, development and evaluation of a power tiller operated vegetable transplanter, International Journal of New Technologies in Science and Engineering 5 (9) (2018) 92–112.
[4] A. Sharma, S. Khar, Design and development of a vegetable plug seedling transplanting mechanism for a semi-automatic transplanter, Sci. Hortic. 326 (2024) 112773.
[5] A. Sharma, S. Khar, Current developments in vegetable transplanters in developing countries: a comprehensive review, Int. J. Veg. Sci. 28 (5) (2022) 417–440.
[6] E. Aykas, R.C. Akdeniz, F. Kömekçi, C. Kömekçi, Determining the field performance and cost analysis of walk behind type semi-automatic hand feed vegetable transplanter, Tarım Makinaları Bilimi Dergisi 13 (3) (2017) 149–154.
[7] K. Khan, S.C. Moses, A. Kumar, The design and fabrication of a manually operated single row multi – crops planter, IOSR J. Agric. Vet. Sci. 8 (10) (2015) 147–158, https://doi.org/10.9790/2380-08102147158.
[8] S.M. Javidan, D. Mohammadzamani, Design, construction and evaluation of semi-automatic vegetable transplanter with conical distributor cup, SN Appl. Sci. 1 (9) (2019) 999.
[9] M.S. Miah, M.M. Rahman, M.A. Hoque, S.M. Ibrahim, M. Sultan, R.R. Shamshiri, T.N. Barna, Design and evaluation of a power tiller vegetable seedling transplanter with dibbler and furrow type, Heliyon 9 (8) (2023) e17827.
[10] D. Choudhury, V.V. Singh, A.K. Dubey, Survey on existing status of seeding/planting method and determination of mechanization need of planting for important vegetable crops in Indi a. Annual Report, Central Institute of Agricultural Engineering (CIAE), Bhopal, Madhya Pradesh, India (1997) 4–7.
[11] Agricultural Census 2015-16, All India Report on Number and Area of Operational Holdings; DAC&FW, Ministry of Agriculture & Family Welfare, GOI, New Delhi, India, 2018.
[12] I.S. Bisht, J.C. Rana, S. Pal Ahlawat, The future of smallholder farming in India: some sustainability considerations, Sustainability 12 (9) (2020) 3751.
[13] DES (2016-17). Digest of Statistics. (Directorate of Economics and Statistics). Department of Agriculture, Cooperation and Farmers's Welfare. Ministry of Agriculture and Farmer's Welfare, Government of India.
[14] J. Dixit, V. Kumar, M. Ali, Development and evaluation of a single row manual vegetable transplanter, Agric. Eng. Today 42 (2) (2018) 58–66.
[15] M.J. Lawrence, D.R. Buckmaster, W.J. Lamont, A pneumatic dibbling machine for plastic mulch, American Society of Agricultural and Biological Engineers 23 (4) (2007) 419–424, https://doi.org/10.13031/2013.23483.
[16] R.L. Bergamo, L.N. Romano, Agricultural machinery and implements design process: guidelines for small and mid-sized businesses, Journal of the Brazallian Association of Agricultural Engineering 36 (1) (2016) 206–216, https://doi.org/10.1590/1809-4430-Eng.Agric.v36n1p206-216/2016.
[17] A. Sharma, S. Khar, D. Chaudhary, P. Thakur, Study of biometric attributes of plug type tomato seedlings pertinent to transplanter design, Indian J. Ecol. 50 (2) (2023) 503–507.
[18] A. Sharma, S. Khar, S. Sharma, J.P. Singh, Investigation of physical traits of brinjal seedlings apropos to the design of a transplanter, Environ. Ecol. 40 (2A) (2022) 476–481.
[19] B.M. Nandede, H. Raheman, A tractor drawn vegetable transplanter for handling paper pot seedlings, Agricultural Mechanization in Asia, Africa, and Latin America 47 (4) (2016) 87–92.
[20] A. Khadatkar, S.M. Mathur, B.B. Gaikwad, A. Pandirwar, D.J. Shrinivas, Biometric properties of plug vegetable seedlings relevant to the design of vegetable transplanter, Journal of Agricultural Engineering 57 (1) (2020) 17–24.
[21] N.C. Pandya, C.S. Shah, Elements of machine design, Charotar Book Stall, Juloi Sadan, Anand, India (1962) 275–285.

[22] M.L. Durga, in: N.G. Acharya (Ed.), Design and Development of Mini-Tractor Drawn Transplanter for Vegetable Crops, Ranga Agricultural University, Guntur, Andhra Pradesh, India, 2018. M.Tech thesis.
[23] M.Z. Iqbal, M.N. Islam, M. Chowdhury, S. Islam, T. Park, Y.J. Kim, S.O. Chung, Working speed analysis of the gear-driven dibbling mechanism of a 2.6 kw walking-type automatic pepper transplanter, Machines 9 (2021) 2–16, https://doi.org/10.3390/machines9010006.
[24] S. Singh, Mechanical Engineer's Handbook, Khanna Publishers, Delhi, India, 2003.
[25] P.C. Sharma, D.K. Aggarwal, Machine Design, Eleventh edition 2006-07, SK Kataria & Sons, New Delhi, 2006 (chapter 21).
[26] M.K. Narang, Development and Evaluation of a Revolving Magazine Type Transplanting Mechanism (Dropping Type) for Vegetable Crops, Punjab Agricultural University, Ludhiana, India, 2010. Ph.D thesis.
[27] A. Singh, Cambridge cb2 8bs, Fundamentals of Machine Design, vol. II, Cambridge University Press, United Kingdom, 2017 (chapter 3 & 8).
[28] V.B. Bhandari, Design of Machine Elements, third ed., McGraw Hill education, pvt ltd, India, 2014 (chapter 23).
[29] M. Hanna, Estimating the Field Capacity of Farm Machines. Ag Decision Maker, File A3-24, PM 696, Iowa State University, 2016. Extension and Outreach, http://www.extension.iastate.edu/agdm.
[30] R.A. Kepner, R. Bainer, E.L. Barger, Principles of Farm Machinery, Ist e-book edition, CBS Publishers & Distributors Pvt. Ltd, New Delhi, India, 2017, p. 17. Chapter-2.
[31] D. Hunt, Farm Power and Machinery Management, tenth ed., Waveland Pr Inc., Long Grove, Illinois – USA, 2007, p. 368. Reissue edition.
[32] K.S. Yadav, A. Bajpay, Nursery pro-trays and its importance in horticulture, The Journal of the Greens and Gardens 1 (2) (2019) 27–28.
[33] O.J. Jorg, M. Sportelli, M. Fontanelli, C. Frasconi, M. Raffaelli, G. Fantoni, Design, development and testing of feeding grippers for vegetable plug transplanters, AgriEngineering 3 (3) (2021) 669–680.
[34] D. Karayel, H. Aytem, The effect of different tillage methods on transplanting quality of potted tomato and watermelon seedlings, Journal of Agricultural Machinery Science 9 (1) (2013) 83–91 (in Turkish with an abstract in English).
[35] D.K. Mohanty, D. Behera, M. Mahapatra, S.K. Swain, Effects of vegetable transplanter press wheel design on soil compaction and seedling establishment, Journal of Agricultural Engineering 54 (1) (2017) 11–20.
[36] S.K. Satpathy, I.K. Garg, Effect of selected parameters on the performance of a semi-automatic vegetable transplanter, Ama, Agric. Mech. Asia, Afr. Lat. Am. 39 (2) (2008) 47.
[37] A.K. Jaiswal, J.P. Singh, S. Tomar, A. Shek, N. Thakur, Effect of seedlings age on growth, yield attributes and yield of tomato (Lycopersicon esculentum mill.), International Journal of Current Microbiology and Applied Sciences 6 (9) (2017) 1521–1524.
[38] K.Y. Kumar, V.N. Reddy, S.C. Moses, R.N. Aalam, S. Singh, Design, development and evaluation of manual vegetable transplanter, Int. J. Curr. Microbiol. App. Sci. 10 (1) (2021) 497–508, https://doi.org/10.20546/ijcmas.2021.1001.061.
[39] H.R. Chavda, P.R. Balas, C. Jadav, V.R. Vagadia, A. Upadhyay, Development and performance evaluation of 3-Jaw manual vegetable transplanter, The Pharma Innovation Journal SP- 11 (7) (2022) 408–412.
[40] P.C. Dihingia, G.V.P. Kumar, P.K. Sarma, P. Neog, Hand-fed vegetable transplanter for use with a walk-behind-type hand tractor, Int. J. Veg. Sci. 24 (5) (2017) 1–20, https://doi.org/10.1080/19315260.2017.1413477.
[41] A. Khadatkar, S.M. Mathur, Design and development of an automatic vegetable transplanter using a novel rotating finger device with push-type mechanism for plug seedlings, Int. J. Veg. Sci. 28 (2) (2022) 121–131.