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Development and Performance Evaluation of Manually Operated Paper Chain Pot Vegetable Transplanter

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A B S T R A C T

Vegetable farming is an important part of Indian agriculture, but manual transplanting of seedlings is laborious, time-consuming and often causes root damage. To address these issues, a manually operated single-row paper chain pot vegetable transplanter was developed and evaluated at IGKV, Raipur. The machine consists of a handle, tray holder, paper pot conveyor, pot lifter, furrow opener, wings, press wheel and back wheels, ensuring uniform placement of seedlings with minimal root disturbance. Biodegradable paper chain pots of 30 mm diameter with 264 pots per set were used. The transplanter achieved an average actual field capacity of 0.0176 ha/h and field efficiency of 70%. The best performance was obtained at 150 mm spacing, 0.5 km/h speed and 20 mm depth, giving 77.9% efficiency and 94.2% survival, while higher speed and deeper depth increased transplanting time and mortality. The operational cost was about Rs. 3150 per hectare with a break-even point of 101 hours per year and a payback period of 1.15 years. Thus, the developed paper chain pot transplanter is eco-friendly, economical and suitable for small and marginal farmers.

Introduction

Vegetable farming plays a vital role in India's agriculture, supporting the livelihoods of millions of farmers. The country grows nearly 175 types of vegetables, with major crops including tomato, onion, chili, brinjal, cauliflower, and cabbage (Kaushik *et al.*, 2020). India is the second-largest producer of vegetables globally, cultivating them on 24.19 million hectares with an annual production of 277.35 million tonnes (National Horticulture Board, 2014). The country contributes approximately 14% of the world's vegetable production, producing 146.55 million tonnes from around 15% of the global area under vegetables (Vanitha *et al.*, 2013). Despite this, India's average vegetable productivity is 17.3 t/ha, which remains slightly below the global average of 18.5 t/ha (Ray and Moses, 2024).

Most vegetables such as cucurbits (*Cucurbita spp.*), beans (*Phaseolus spp.*), okra (*Abelmoschus esculentus*), and leafy greens are established by direct sowing, crops like tomato (*Solanum lycopersicum*), brinjal (*Solanum melongena*), and peppers (*Capsicum spp.*) are first raised in nurseries and then manually transplanted into the field

(Prasanna and Raheman, 2011). Transplanting ensures uniform spacing, better plant establishment, and higher yields. However, manual transplanting is labor-intensive, time-consuming, and physically demanding, often requiring workers to bend for long periods, separate seedlings one by one, and plant them in soil (Ray and Moses, 2024). The reliance on plastic seedling trays can also damage roots and contributes to environmental concerns due to non-biodegradable waste (Briassoulis, 2023).

To address these challenges, paper chain pot transplanters provide a low-cost, eco-friendly solution. These transplanters allow seedlings to be transplanted with intact roots, improving survival and growth while reducing labor and physical strain (Hwang *et al*., 2022).

The use of biodegradable paper pots minimizes plastic waste, ensures precise plant spacing, and promotes efficient resource use. Such tools are particularly suitable for small and marginal farmers, supporting sustainable vegetable production and improving overall productivity and crop quality.

Therefore, the present study was undertaken to develop a manually operated paper chain pot vegetable transplanter for precision transplanting of seedlings.

Materials and Methods

The study was conducted at the Swami Vivekanand College of Agricultural Engineering and Technology and Research Station, Indira Gandhi Krishi Vishwavidyalaya (IGKV), Raipur, Chhattisgarh. The work focused on the development and performance evaluation of a manually operated paper chain pot vegetable transplanter.

Study of Biometric Properties of Seedlings

The biometric properties of seedlings play a significant role in determining their suitability for transplanting. Parameters such as plant height, stem diameter and weight are considered essential for ensuring proper handling, placement, and establishment in the field. In the present study, these parameters were recorded for hyacinth bean (*Sem*) and yardlong bean (*Barbatti*) seedlings.

The observations were taken using a graduated scale for height, a vernier caliper for stem diameter and a digital balance for seedling weight.

Development of Paper Pot Transplanter

A manually operated single-row vegetable transplanter was developed to facilitate precise and uniform planting of seedlings. The equipment comprises a handle, tray holder, paper pot conveyor, pot lifter, furrow opener, wings, back wheels, and a press wheels. The handle allows smooth operation, while the tray holder provides firm support to the seedling tray. The furrow opener creates uniform trenches into which seedlings are guided by the paper pot conveyor.

The wings cover the seedlings by returning soil into the furrow, and the pot lifter ensures safe transfer without mechanical injury. The pressure wheel compacts the soil around the seedlings to promote proper establishment, while the back wheels provide stability during operation. The detailed specifications of the transplanter are presented in Table 1 and the developed transplanter is shown in Figure 1.

Paper Chain Pot

As paper chain pots are not available in India, they were imported from Japan (M/s Plus Y'S Co. Ltd., Product ID LP 303 10) for this study. Each set consists of 264 biodegradable pots, 30 mm in diameter and height, arranged in a honeycomb chain pattern to optimize nursery space utilization and promote uniform root development.

A locally made version using thermal paper rolls was also developed for trials, functioning similarly and allowing direct field transplantation with minimal root disturbance and labor.

Performance Evaluation

The performance of the developed transplanter was evaluated using three independent variables: speed of operation with levels 0.5, 0.75, and 1.0 km/h, plant to plant spacing with levels 100 and 150 mm and depth of placement with levels 20, 30, and 50 mm. The dependent variables were actual field capacity, theoretical field capacity, field efficiency, transplanting time, plant mortality and seedling survival.

The experimental data were analyzed using a factorial randomized block design with 18 treatments and three replications.

Calculation of Dependent Parameters

Theoretical field capacity (TFC)

Theoretical field capacity depends on the machine's total working width and its average speed in the field.

$$\text{TFC}\left(\frac{\text{ha}}{\text{h}}\right) = \frac{\text{width(m)} \times \text{Speed}\left(\frac{\text{m}}{\text{h}}\right)}{1000} \quad \dots(1)$$

Actual field capacity (AFC)

The actual output in terms of area covered per hour is expressed as the effective field capacity, which includes both the time spent on actual work and time lost in activities like turning, loading and adjustment.

$$\text{Effective field capacity}\left(\frac{\text{ha}}{\text{h}}\right) = \frac{\text{Area covered}}{\text{Time taken}} \quad \dots(2)$$

Field efficiency (FE)

Field efficiency is the ratio of effective field capacity to theoretical field capacity.

$$\text{Field Efficiency (\%)} = \frac{\text{EFC}}{\text{TFC}} \times 100 \quad \dots(3)$$

Plant mortality

Plant mortality is defined as the percentage of seedlings that do not survive after transplanting.

$$\text{Plant mortality (\%)} = \frac{\text{Sum of plant died}}{\text{Total plant}} \times 100 \quad \dots(4)$$

Survival plant rate

It denotes the number of seedling survived after transplanting. It expressed in percentage

$$\text{Survival plant rate (\%)} = \frac{\text{Sum of plant survived}}{\text{Total plant}} \times 100 \quad \dots(5)$$

Results and Discussion

The results obtained from the experiments are presented and discussed in detail in the following section. The biometric properties of seedlings, along with the effects of different independent parameters on the performance of the vegetable trasnplanter, are also explained.

Biometric Properties of Seedlings

The biometric properties of hyacinth bean (*Sem*) and yardlong bean (*Barbatti*) seedlings, such as height, weight, and stem diameter, increased steadily with the number of days. As shown in Table 2, this uniform rise indicates healthy growth and proper development of the seedling.

Field capacity of the trasnplanter

The theoretical field capacity of the transplanter ranged from 0.0150 to 0.0276 ha/h at speeds of 0.65–1.20 km/h, while the actual field capacity obtained from field tests varied between 0.0103 and 0.0213 ha/h, with an average of 0.0176 ha/h.

Effect of plant to plant spacing depth of showing and operating speed on field efficiency of transplanter

The interactive effect of plant spacing, sowing depth, and operating speed on the field efficiency of the paper chain pot transplanter was significant at the 5% level of significance. The highest efficiency of 77.9% was recorded at 150 mm spacing, 0.5 km/h speed, and 20 mm sowing depth, while the lowest efficiency of 59.6% occurred at 100 mm spacing, 0.75 km/h speed, and 50 mm depth. These results indicate that wider spacing, slower speed, and shallower sowing depth improve field efficiency.

Effect of plant to plant spacing depth of showing and operating speed on survival plant rate of seedling

The interactive effect of plant spacing, sowing depth, and operating speed on the survival rate of seedlings was found to be significant at the 5% level of significance.

The highest survival of 94.2% was recorded at 150 mm spacing, 0.5 km/h speed, and 20 mm sowing depth, whereas the lowest survival of 75.36% was observed at 150 mm spacing, 1.0 km/h speed, and 30 mm depth. Overall, slower operating speed and shallower sowing depth enhanced the survival rate of seedlings, as shown in Figure 4.

Table.1 Specifications of developed paper chain pot transplanter

S. No.		Description	Specifications
1		**Type**	**Single-row manually operated**
2		**Power required**	**1 man**
3		**Seedling metering mechanism**	
	(i)	Type	**Paper chain pot**
	(ii)	Number of pots	**264**
	(iii)	Diameter of pot (mm)	**30**
	(iv)	Pot to pot distance (mm)	**100, 150**
4		**Furrow opener**	
	(i)	Type	**V shape**
	(ii)	Depth of placement of seedling (mm)	**20, 30, 50**
5		**Press wheels**	
	(i)	Type	**Circular**
	(ii)	Diameter(mm)	**100**
	(iii)	Width (mm)	**30**
6		**Weight of machine (kg)**	**13**
7		**Overall dimensions (mm)**	**1667×420×929**

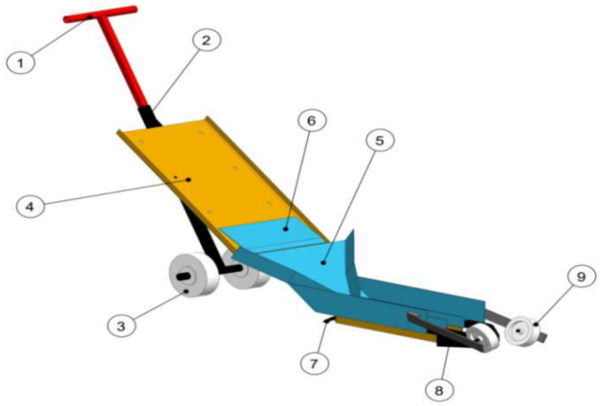
Table.2 Biometric properties of seedlings

S. No.	Properties	Hyacinth bean (*Sem*)			Yardlong bean (*Barbatti*)		
		2nd Day	4th Day	6th Day	2nd Day	4th Day	6th Day
1	Height of seedlings (mm)	31.84	70.83	127.28	23.35	60.95	109.83
2	Stem diameter (mm)	0.96	1.89	2.77	0.80	1.63	2.26
3	Weight of seedlings (g)	0.28	0.8	1.29	0.23	0.69	1.11

Table.4 Performance of Developed Paper Chain Pot Transplanter

S. No.	Dependent Parameters	Performance
1	Actual field capacity (ha/h)	0.0176
2	Theoretical field capacity (ha/h)	0.0219
3	Field efficiency (%)	70.00
4	Plant mortality (%)	12.92
5	Survival plant rate (%)	86.51
6	Transplanting time (min/row)	0.94

Figure.1 Paper chain pot transplanter



S.No.	Component
1	Handle
2	Connecting rod
3	Back wheel
4	Tray holder
5	Paper pot conveyor
6	Paper pot lifter
7	Furrow opener
8	Wings
9	Press Wheel

Figure.2 Performance evaluation of paper chain pot transplanter

Figure.3 Effect of plant to plant spacing depth of showing and operating speed on field efficiency

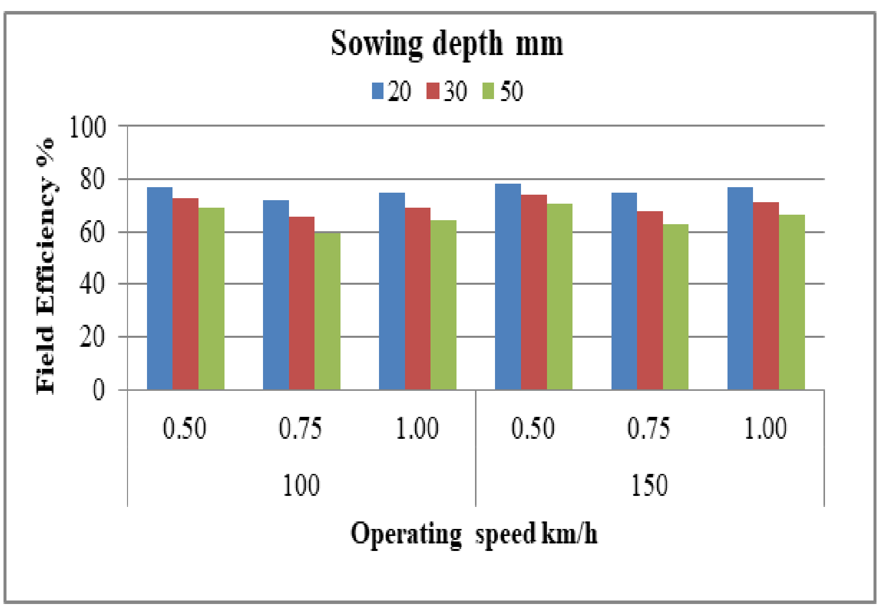


Figure.4 Effect of plant to plant spacing depth of showing and operating speed on survival plant rate of seedling

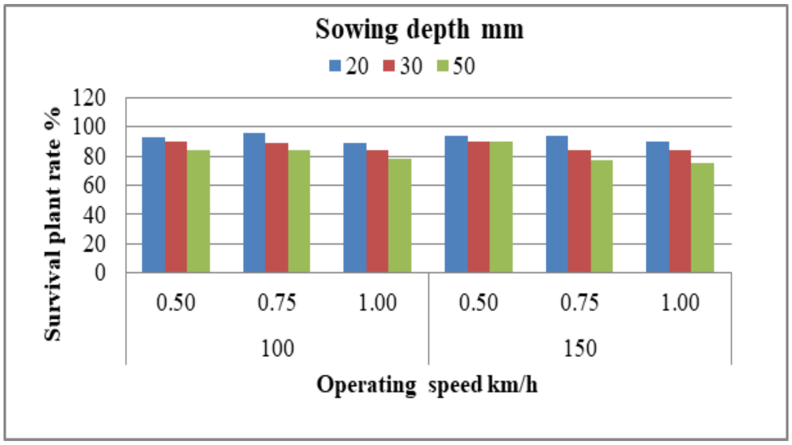


Figure.5 Effect of plant to plant spacing depth of showing and operating speed on plant mortality of seedling

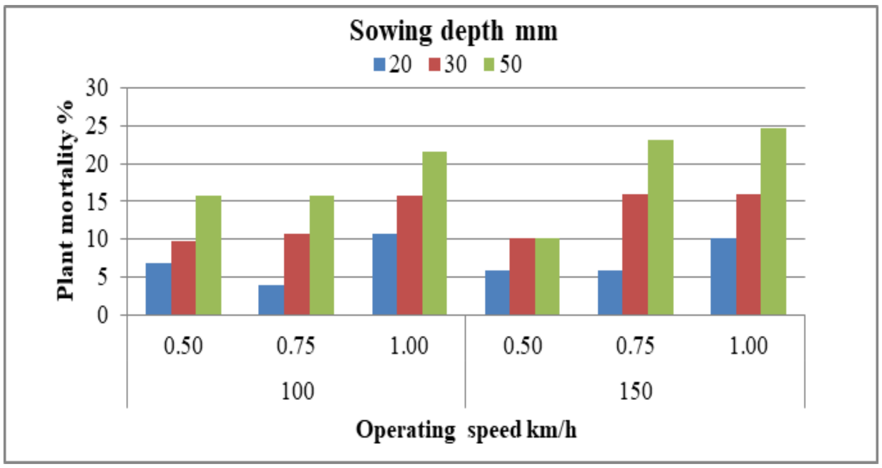
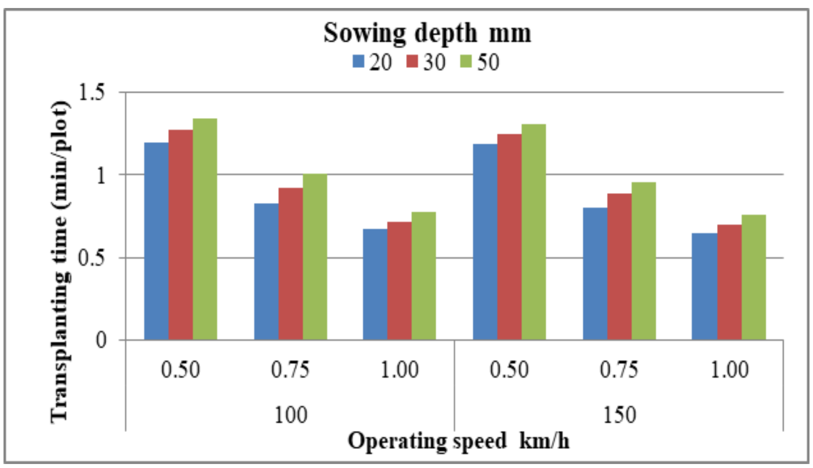


Figure.6 Effect of plant to plant spacing depth of showing and operating speed on **transplanting time**



Effect of plant to plant spacing depth of showing and operating speed on plant mortality of seedling

The interactive effect of plant spacing, sowing depth, and operating speed on plant mortality of seedlings was found to be significant at the 5% level of significance. The highest mortality of 24.64% was observed at 150 mm spacing, 1.0 km/h speed, and 50 mm depth, whereas the lowest mortality of 3.92% was recorded at 100 mm spacing, 0.75 km/h speed, and 20 mm depth. Overall, higher operating speed and greater sowing depth increased mortality, while slower speed and shallower depth reduced it, as shown in Figure 5.

Effect of plant to plant spacing depth of showing and operating speed on transplanting time

The interactive effect of plant spacing, sowing depth, and operating speed on transplanting time was found to be significant at the 5% level of significance. The highest transplanting time of 1.34 minutes per row was recorded at 100 mm spacing, 0.5 km/h speed, and 50 mm depth, whereas the lowest time of 0.65 minutes per row was observed at 150 mm spacing, 1.0 km/h speed, and 20 mm depth. Overall, closer spacing, slower operating speed, and greater sowing depth increased transplanting time, while wider spacing, higher speed, and shallower depth reduced it, as shown in Figure 6.

Cost Analysis

The manually operated paper chain pot transplanter had a capital cost of Rs 5000. The operational cost was estimated at 3150 Rs/ha, with fixed costs including depreciation, interest, and shelter, and variable costs covering labour and maintenance. The break-even point has been calculated as 101 h/ year, and the payback period is 1.15 years. These results indicate that the transplanter is economically feasible and appropriate for use under farmers' field conditions.

In conclusion, the manually operated paper chain pot vegetable transplanter showed satisfactory performance under field conditions, with an actual average field capacity of 0.0176 ha/h. The best results were obtained at 150 mm plant spacing, 0.5 km/h operating speed, and 20 mm planting depth, where field efficiency was 77.9% and seedling survival reached 94.2%. The average field efficiency recorded was 69.72%, plant mortality was 12.92%, and seedling survival rate was 86.51%, with an average transplanting time of 0.94 min/row. Higher operating speeds and deeper planting depths increased transplanting time and seedling mortality, with maximum mortality of 24.64% and minimum survival of 75.36% under less favorable conditions. The developed transplanter weighs 13 kg with overall dimensions of 1667 × 420 × 929 mm. The machine is suitable for single-row planting and can hold 264 biodegradable paper pots of 30 mm diameter, maintaining a spacing of 100–150 mm for proper plant population and minimal root disturbance. Economic analysis showed an operational cost of 3150 Rs/ha, a break-even point of 101 h/year, and a payback period of 1.15 years, confirming its economic feasibility for small and marginal farmers.

Author Contributions

V. M. Victor: Conceived the original idea and designed the model the computational framework and wrote the manuscript; Kshama Sahu: Formal analysis, writing review and editing; Bharat Lal Verma: Validation, methodology, writing—reviewing

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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