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Development and performance evaluation of a manually operated single-row vegetable transplanter

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ABSTRACT

Vegetable transplanting involves digging holes by hand at the desired spacing, placing seedlings, and packing them with soil or soil mixed with manure. This process is time-consuming, tedious, labour-intensive, and expensive. High labour demands and shortages during the peak transplanting season cause delays and affect timely operations. Field experiments were conducted using three transplanting methods (VT_1 , VT_2 , and manual transplanting) with three replications. Two manually operated, low-cost vegetable transplanters made of different materials were developed and tested for transplanting plug-and-place tomato seedlings. These transplanters consist of various components, such as a hopper, handle, seedling delivery tube, jaw opening lever, and jaw mouth; however, each transplanter's weight differed. The two vegetable transplanters were compared with 11 workers using the manual transplanting technique for 60×45 cm crop spacing in tomato crops. The weight of the PVC transplanter (VT_2) was 19% less than that of the alloy steel vegetable transplanter (VT_1). The seedling transplanting rates per minute were 8, 14, and 16 for manual transplanting, VT_1 , and VT_2 transplanters, respectively. The average operating speeds of VT_1 , VT_2 , and manual transplanting were 0.564, 0.55, and 0.240 km/h, respectively. The field efficiencies recorded with manual transplanting, VT_1 , and VT_2 were 62.50%, 70.92%, and 79.69%, respectively. The transplanting cost was reduced by 56.33% compared with conventional manual transplanting under the experimental conditions. The ergonomic evaluation for transplanters was carried out with 11 workers. The mean heart rate recorded with the PVC transplanter was 104.00 ± 15.10 beats/min, whereas it was 121.09 ± 8.53 beats/min during manual transplanting.

Keywords: Vegetable Transplanter, Field capacity, Cost of transplanting, Field efficiency, Manual Transplanting, Time saving

Introduction

India is the world's second-largest producer of vegetables, with total production reaching approximately to 219.67 million metric tonnes as a substantial share of global output (Agricultural and Processed Food Products Export Development Authority, 2026). Vegetable cultivation is an important component of Indian agriculture, particularly for small and marginal farmers, and plays a significant role in food security, nutrition and farm income. The demand for vegetables is expected to increase substantially in the coming years, necessitating improvements in production practices and mechanization. Major vegetable crops such as tomato, brinjal, chilli, cabbage and cauliflower are generally raised in nurseries and subsequently transplanted to the main field. Manual transplanting is a labour-intensive, time-consuming and drudgerous operation, involving repetitive bending, squatting and manual placement of seedlings. It requires considerable labour and may result in non-uniform plant spacing, delayed transplanting and increased physical strain on workers. The manual handling of seedlings can also cause root damage, affecting crop establishment.

A transplanter is an agricultural machine used for transplanting seedlings into the field. This is very important as it reduces the time taken to transplant seedlings (when compared to manual transplanting), thus allowing more time for harvesting. It also reduces the use of manual energy. The transplanting operation is one of the most labour-intensive operations in vegetable production. Kumar, G. V. P., & Raheman, H. (2008) [1] stated that vegetable cultivation is largely done by hand in India and most developing countries and incurs large investments in labour, time, and cost. Several types of vegetable transplanters are used for transplanting seedlings, including manually operated and mechanical transplanters. In mechanical vegetable transplanters, semi-automatic, automatic, and robotic types are used. Mechanical transplanters, such as semi-automatic transplanters have been developed till now India. About 15-72 seedlings per minute have been reported by various researchers. However, these transplanter costs are very high and are operated by power tillers/tractors, which is not feasible for small farms. Malunekar et al. (2014) designed and developed a hand-held vegetable transplanter evaluated for different vegetable crops and observed from trials was 0.02 ha h^{-1} and field efficiency was 82.30%. Satpathy et al. (2008) [2] Studies were conducted on a two-row semi-automatic vegetable transplanter to assess its performance at different speeds, soil moisture, and seedling edges with respect to plant missing, planting angle, planting depth, plants in lying down position,

and plant mortality for two vegetable crops, namely tomato and Chilli. The best transplanting results were obtained at 10% soil moisture content with five-week-old tomato and 17-19-week seedlings in Chilli crop. The machine could be operated at 1 and 1.2 km/h. speed with a missing – 3-4 %.

Patil et al. (2015) [3] developed transplanter which having transplanting capacity observed from the trial was 0.02 ha/hr, the theoretical field capacity was 0.0243 ha/hr, and the field efficiency was 82.30%. The cost of the operation was found comparatively lower than that of the traditional method of transplantation. From visual observation, we observed that there was no damage to the seedlings during operation. **Jadhav et al. (2025)** [4] highlighted existing research highlights the effectiveness of fully automatic transplanters but also points out their limited accessibility for marginal farmers. **Dihingia et al. (2018)** [5] developed two-row vegetable transplanter for transplanting soil block seedlings was developed as matching equipment for a walk-behind hand tractor. The developed vegetable transplanter has the potential of saving 83%–85% of time involved with seedling establishment and 66%–69% labour involved in conventional transplanting in market gardens. **Kanakam Y.K. (2021)** [6] designed, developed and evaluated of manual vegetable transplanter on two different types of vegetable crops i.e., tomato and chilli. The cost of operation was reduced with the developed prototype and saving in cost of operation was found to be 56.62% for tomato and 42.17% for Chilli over conventional method.

Although tractor-operated and automated vegetable transplanters are available, their high initial cost, size and power requirements may restrict their adoption by small and marginal farmers and in small or fragmented fields. Therefore, there is a need for simple, low-cost and lightweight manually operated vegetable transplanters suitable for Indian farming conditions. Such equipment can provide an appropriate level of mechanization by reducing labour requirement and operator drudgery, improving transplanting uniformity and timeliness, and enhancing the ergonomic performance of the operation.

Previous studies have mainly focused on machine performance; limited information is available regarding lightweight material modification combined with ergonomic assessment for smallholder conditions. Mechanical transplanters, including semi-automatic models, have been developed in India but; the adoption of tractor-operated and automated vegetable transplanters is limited among small and marginal farmers due to their high initial cost, power requirements and relatively large size. Conventional transplanting of tomato, brinjal and Chilli is labour-intensive, requiring about 185 man-h ha⁻¹ under raised-bed planting and 260 man-h ha⁻¹ under flat-bed planting. Therefore, the development of an affordable, lightweight and manually operated transplanter is essential for small and fragmented farms. Such a machine can reduce labour requirement and operator drudgery while improving transplanting uniformity and timeliness. Accordingly, a manually operated single-row vegetable transplanter was developed and evaluated at the Department of Farm Machinery and Power Engineering and tested for transplanting various vegetable crops.

Materials and Methods

A preliminary assessment was conducted required on manual transplanting methods. It was observed that the most operations under vegetable cultivation are accomplished manually. These operations are accomplished in a kneeling or squatting posture. They are more tedious, uncomfortable, tiresome, and drudgery-prone. Therefore, a low-cost manually operated single-row vegetable transplanter was developed in the Department of Farm Machinery and Power Engineering, College of Agricultural Engineering and Technology, Parbhani for transplanting plug-type seedlings on ridges. An attempt was made to reduce the manual effort required for vegetable trans-

planting by developing a manually operated vegetable transplanter. The components of the developed transplanter, such as the frame, seedling feeding pipe, hand lever, jaw assembly, and connecting linkages, were designed and fabricated. The developed Vegetable Transplanter was used for transplanting different tomato plug seedlings at VNМКV, Parbhani. A field performance test of the vegetable transplanter was conducted to analyze the working efficiency of transplanting seedlings. Machine performance parameters and Operational cost of manually operated vegetable transplanter was calculated by standard procedure.

Design considerations for vegetable transplanter

Following agronomical factors are required to be considered for designing a prototype

1. Dimension of seedling

The dimension of seedling is important to decide the diameter of hollow pipe, height of jaw and apex angle. Canopy of seedling is considered to decide the diameter of hollow pipe, the average size of canopy is required to avoid clogging in hollow pipe, also stage of seedling decide the height of jaw. The height of seedling should not be more than 20 cm.

2. Dimension of coco peat

The height and diameter of seedling pot is important consideration in hand held vegetable transplanter; the dimension of seedling pot is 5 cm in width and height. Paper pots of 65 cc in volume filled with a mix of 25% vermicompost, 100 cc in volume filled with a mix of 50% vermicompost, and 81 cc in volume filled with a mix of 33% vermicompost, in combination with equal parts of sand and top soil were most suitable for production of good quality transplants of tomato, eggplant, and chili pepper, respectively (**Kumar et al., 2010**) [7].

3. Preparation of mulch bed

The height of the mulch bed is important to decide the height of the implement for human comfort. The dimension of mulch bed is 20 cm in height and 60 cm in width.

Table 1. Specification of Pro-tray used for growing vegetable seedlings

Sr. No.	Parameters	Dimensions
1.	Tray dimensions (length × width), cm	(49×31)
2.	No of seedling in a tray	104
3.	Plant height with potting mixture, cm	18
4.	Height of potting mixture, cm	3
5.	Shape of tray pot	Conical
6.	Top diameter of tray pot, cm	2.8
7.	Bottom diameter of tray pot, cm	1.9
8.	Shape of tray	Rectangular
9.	Weight of seedling, gm	8.1
10.	Weight of tray, kg	1.2

Design of various components of manually operated vegetable transplanter

Seedling feeding pipe

The seedling feeding pipe was made up of PVC and the diameter measured was 7.5 cm, which was calculated as approximately 1.5 times the root media maximum dimension (plug/pot seedlings) when the plant in upright condition i.e., 30 to 40 mm. The height of pipe was set as 80 cm which was lower than 5th percentile value of standing elbow height of Indian women worker (i.e., 80 cm) for easiness in operation (Chaturvedi, S., et al., 2023). The effort can be made when the elbow angle of 100–110°.

Handle

Table 2. Design Considerations considered for vegetable transplanter

Name of the part	Design requirement
Diameter of the seedling delivery tube	Canopy (Floral Spread) of the seedlings
Size of jaw mouth	Height of seedlings
Height and thickness of the jaw	Depth of penetration
Distance between clutch lever and handle	Ease in operation
Various parts of the transplanters associated with height and posture	Anthropometric dimensions
Overall height of the transplanter	
Handle length	
Hand grip span	

The handle was mounted at top of the seedling feeding pipe, made of mild steel pipe and opposite to movable jaw which was at the bottom of pipe. It was used to control, hold and penetrate the jaw in the soil bed. Grandjean (1981) [8] reported that a comfortable range of elbow angle should be 100-110°. On the basis of this angle, the height of the handle was determined as 89 cm to accommodate larger population on 5th percentile value for maximum work efficiency. The height of handle from ground was fixed on the basis of average standing elbow leg length operator i.e. 82 cm for VT₁ and 85 cm VT₂ and diameter as 1.83 cm was decided on the basis of average hand grip of human and length of handle was kept 13.6 cm for VT₂.

Jaw assembly

It is a soil engaging part of equipment, which makes opening for placing the seedling. The length of jaw was 12 cm with top width of 6.5 cm. The jaw was fabricated with two sections from Alloy steel, one section fixed to the seedling feeding pipe and other one was movable against the axis provided at top of jaw. This movable section of the jaw was fitted with stud and spring mounted inside at one end to regain its closed position against gauge wire. The included angle between the two sections was maintained at 215.5°. The complimentary angle to this, sometimes named as apex angle 2θ, which is inclined angle formed between the two edges, ranges from 36° to 60° for proper penetration of implement into the soil; therefore, apex angle of jaw was taken as 47.26°.

Lever

The lever was used to operate the jaw, which was made up of mild steel. The length of lever was 140 mm and 110 mm respectively for VT₁ and VT₂, width was 20 mm and the thickness of lever was 3 mm. A wire is provided to give leverage to open the soil by jaw.

Space Marker

The marker was provided up to 60 cm marking to indicate the location of seedling to be transplanted. In the present equipment, there was provision to mark laterally as well as longitudinally. This can be adjustable as per the spacings of crop. The technical specifications of the manually operated single row transplanter.

Hand grip:

The diameter of handle is decided according to the average hand grip of human and also to maintain the distance between handle and lever which should not exceed 5.07 cm. The grip span of the jaw-opening lever was fixed at and 5 cm in VT₁ and 5.05 in VT₂ cm based on the 5th percentile grip-span value reported for Indian agricultural workers, thereby facilitating operation by users with smaller hand dimensions. (Khogare *et al.*, 2011) [9]

Apex angle

The apex angle (2θ) is the included angle formed between the two edges of the jaw. According to Patil *et al.* (2015) [3], an apex angle ranging from 36° to 60° is considered suitable for proper penetration of an implement into the soil. Based on this recommended range and the design requirements of the transplanter, an apex angle of 47.26° was selected for the jaw.

Work quality

The formation of dug and hole in the plastic mulch is tedious job. Manual transplanting by traditional method is a labourious and has to carry the seedlings tray along with him and needs more time in maneuverability. Developed machine provided the combination of operation at a time such as formation of hole, placing of seedling, covering the soil, marking for transplanting, carrying the ability of pro-tray having provision of to place the seedling on the developed prototype. The hole prepared by jaw is of uniform in size and depth. It facilitates the hole formation, putting of seedling in hole, covering the soil carrying the seedling along with machine, and spacing making operation in standing posture and help to increase the forward speed operation which result in higher capacity and increase the efficiency of the labour at reduced efforts.

Working principle

VT₁

VT₂

Working principle of the machine is one has to hold the prototype in vertical position with handle and as the jaw in a closed position to the height of 15-30 cm and allow to fall or press it to penetrate into soil bed, one seedling has to be picked up from tray and put it in to the seedling feeding pipe, it will be dropped and held into the jaw from inside. Then, pulling the lever towards handle to open the jaw inside the soil and the moment the jaw is opened the seedling resting inside the jaw will drop by gravity into the pit/hole made by jaw. Lift the transplanter lever in pressed position (jaw open) and the soil accumulated at periphery of jaw rollback towards the root zone of seedling thus stabilizing the seedling in the pit/hole and covering the seedling root zone by soil. The different components were designed based on the seedling characteristics (viz., Dimension of seedlings, soil root containment), human subject strength, reach, clearance limits (viz. Operating force requirement, diameter and clearance between handle and lever, height of equipment), working environment (soil cone index, raised bed /ridge/ mulch).

Figure 1. CAD drawing of vegetable transplanter and developed Prototypes of vegetable transplanter (VT₁ and VT₂)

Table 3. Specifications of manually operated vegetable transplanter

Sr. No.	Specification parameter	Existing vegetable transplanter (VT ₁)	Modified vegetable transplanter (VT ₂)
1	Length of transplanter, cm	90	93
2	Length of jaw, cm	11	12
3	Length of planter without jaw, cm	78	80
4	Top width of jaw, cm	6.5	6.5
5	Outer diameter of pipe, cm	7.5	7.5
6	Inner diameter of pipe, cm	6.9	7.1
7	Thickness of pipe, mm	3	2

(continued on next page)

S _r . No.	Specification parameter	Existing vegetable transplanter (VT ₁)	Modified vegetable transplanter (VT ₂)
8	Diameter of hole punched in soil, cm	10	10
9	Inner Diameter of handle, mm	-	16.88
10	Outer diameter of handle, mm	25	18.82
11	Length of handle, cm	16	13.6
12	Distance between handle and lever, cm	5	5.05
13	Spring length (min), cm	13.3	14.2
14	Spring length (max), cm	14.1	15.2
15	Height of handle from ground, cm	82	85
16	Height of lever from ground, cm	75.2	79
17	Lever length, cm	14	11
18	Diameter of lever, cm	1.4	1
19	Thickness of lever, mm	-	1.5
20	Thickness of connecting rod, mm	5.99	5.66
21	Weight of machine (with marker), kg	2.950	2.400

Testing of developed vegetable transplanter at experimental field

i. Measurement of machine performance parameters

Seedlings delivered per minute were calculated by observing the average time required for transplanting two seedlings in second, the for-

mula of which is given as:

Seedlings delivered $\text{min}^{-1} = 60 / t$, (Nandede *et al.*, 2017) ^[10]

Where, t = average time required for one seedling

ii. Theoretical field capacity of the transplanter was calculated by using following equation:

$$\text{Theoretical Field capacity (ha/h)} = (N \times W \times S) / 10$$

Where, N - No. of Rows covered in single pass

For ha h^{-1} :

$$\text{TFC} = (W \times S) / 10$$

where:

W = width (m)

S = speed (km h^{-1})

iii. Actual field capacity: Actual field capacity was calculated based on area covered and actual time taken for covering the area including the time lost in turning, seedling tray collection time for transplanting.

$$\text{Actual Field Capacity (ha/h)} = \frac{\text{Actual Area covered}}{\text{Actual time taken}}$$

iv. Field efficiency was calculated from theoretical and effective field capacity by using following formula Field efficiency (%) = $\frac{\text{AFC}}{\text{TFC}}$

Where, T.F.C. - Theoretical field capacity, ha/hr, E.F.C - Effective field capacity, ha/hr

iv. Energy expenditure rate (KJ/min)

For calculation of Energy Expenditure Rate from heart rate, the Varghese *et al.* (1994) ^[11] equation was used as follows:

$$\text{EER (kJ/min)} = 0.159 \times \text{HR (beats/min)} - 8.72$$

v. Percentage Grip strength = $(S_r - S_w) / S_r \times 100$

S_r = Strength of muscles before work; S_r

S_w = Strength of muscles after work

vi. Labour required

Labour required was calculated in terms of the man hours required for transplanting in one-hectare area by taking inverse of actual field capacity assuming one operator per machine.

vii. Cost of operation

The labour charges were considered as Rs. 45/h. Hence the labour cost required (Rs.) for one-hectare transplanting was calculated by multiplying man hours required for transplanting in one-hectare area with 45.

Results and discussion

The Department of Farm Machinery and Power Engineering at CAET, Parbhani, developed two transplanters with varying construction materials and slight design modifications. These were tested on Tomato crop at the VNMKV campus experimental Farm in Parbhani during 2020-21 and 2021-22. The study targeted on evaluating machine performance, transplanting costs, and the economic aspects of

the two implements, alongside an ergonomic analysis. An ergonomic assessment of the vegetable transplanter was carried out in comparison to manual transplanting methods. This evaluation aimed to determine energy expenditure rates, Overall Discomfort Rating (ODR), musculoskeletal issues, workload, and grip strength reduction during operation. Participants were familiarized with the experimental procedures and instructed to rest adequately before beginning the tasks. To minimize data recording errors, transplanting operations were repeated three times by the participants for Tomato crop.

Clogging and damage percentage

The missing plants which got clogged into jaw of the implement during transplanting. Seedling clogging percentage rate for VT_1 and VT_2 was observed as 6% and 5.6% respectively in Tomato crop. No mechanical damage was observed if seedlings are healthy and floral spread (canopy) is optimum.

Mortality rate

The mortality rate was found more if not irrigated immediately after transplanting. The Mortality rate was more with transplanter operation; whereas it was lower in manual transplanting. In manual trans

planting, the better plant standing rate *i.e.* 7 % higher than transplanter operations (82 % in VT₁ and 84% in VT₂) were observed.

Table 04. Selection of Experimental site and agronomical considerations

Sr. No.	Particulars	Experimental Details
01	Experimental Location	VNMKV Experimental farm
02	Type of soil	Black Soil
03	Experimental Crops	Tomato
04	Average Age of Seedlings	21-23 Days (> 3 weeks)
05	Crop Spacing	60 * 45 cm
06	Experimental Area	18 sq-m (Each plot) (Size- 1.8m *10 m) No. of Plots -09 =Total Area = 162 sq.m
07	Treatments	3 No. <i>T</i> ₁ - <i>VT</i> ₁ - Alloy steel vegetable transplanter <i>T</i> ₂ - <i>VT</i> ₂ - PVC Made transplanter <i>T</i> ₃ - Manual or Conventional transplanting method
08	No. of Replications & Observations	3 replications × 3 treatments = 9 observations

Sr. No.	Particulars	Experimental Details
09	No. of subjects /Workers for ergonomic evaluations	11 (Females) group age- 25 to 45
10	Statistical design used for ergonomic evaluation	Paired <i>T</i> -test, Randomized Complete Block design
11	Type of seedlings used	Pro-trays Plug type
12	Soil moisture	15-17 %
13	Type of farm equipment used for land preparation	Rigid type Cultivator, Rotavator, Two bottom Ridger
14	No. of Plants per ha	37037/ha (60 cm *45 cm)
15	No. of weak seedlings per tray	10 %

Field performance of vegetable transplanters

The transplanting rate in PVC made transplanter was more than steel made transplanter as the weight of the implement was less than Alloy steel based transkanter. The average effective field capacity of the vegetable transplanter for transplanting seedlings was 0.0263 ha/hr which was more than traditional transplanting method and transplanter made up with Alloy steel material. The average cost of operation was more for transplanting chili seedlings as the crop spacing varied and no. of plants per ha were more. The average field efficiency of manually operated vegetable transplanter was found 62.50%. (Table 05).

Table 05. Performance parameters of manually operated vegetable transplanters

Sr. No	Parameter	Alloy Steel Transplanter (VT ₁)	PVC Transplanter (VT ₂)	Manual Method
1	Seedling rate per minute	14	16	08
2	Operational Speed, km/hr	0.564	0.55	0.24
3	Theoretical field capacity, ha/hr	0.03384	0.0330	0.0144
4	Actual field capacity, ha/hr	0.02400	0.0263	0.0090
5	Field Transplanting efficiency, %	70.92%	79.69%	62.50%
6	No. of operators required to operate transplanter (including seedling transport)	02	02	Min. 03
7	Cost of operation, Rs/hr	67	57	142
8	Cost saving over manual method of transplanting, %	52.81%	59.85%	--

Table 06. Comparison between Transplanting Costs of vegetable transplanters with traditional transplanting method.

Sr. No.	Name of the Parameter	Vegetable transplanter (Alloy steel) VT ₁	Vegetable transplanter (PVC) VT ₂	Traditional
1	Prototype fabrication cost (Rs.)	1900	1750	Human labour with Khurpi
2	Life of machine, years	4 years	3 year	-
3	Working hr. per year (hr.)	162	162	-
4	Type of labour required	Semi-skilled	Semi-skilled	(Unskilled)
5	Total labour required, man-h ha ⁻¹	43	37	144
6	Total cost of operation (Rs./ha)	1992	1710	4516

Ergonomic study of developed vegetable transplanter

Selection of subjects

For the ergonomic evaluation of manually operated transplanter, 11 healthy agricultural workers aged between 25-45 without any past history of major disease were selected. The ergonomic evaluation

with a limited sample size (*n* = 11) agricultural workers / subjects aged between 25-45 without any past history of major disease were

selected. Average anthropometric data of selected subjects are shown in (Table No. 7).

Musculo-skeletal problems (MSP)

Musculo-skeletal problems and posture were evaluated by asking the respondents as to where they felt pain in their body after transplanting with traditional and vegetable transplanter technology. It showed that that transplanting with traditional method in strenuous posture causes severe pain in shoulders, upper back, hands and fingers and the farmers perceived the task as heavy. On the contrary using single row manual vegetable transplanter induced moderate discomfort and light pain in shoulders, hands and arms. They were relieved from back pain as standing and bending posture eliminated and rating of perceived exertion was reported as moderate with use of transplanter and heavy with manual transplanting method.

Body part discomfort score (BPDS)

The calculation procedure of BPDS was based on the Body Part Discomfort Score (BPDS) technique of Corlett *et al.* (1976) [12]. To measure the localized discomfort, the subject's body was divided into 27 regions. A body mapping similar to that of body mapping was made with thermo-col to have a real and meaningful rating of perceived exertion of the subject. The subject was asked to mention all body part with discomfort, starting with the wrist, the second wrist and so on until all parts have been mentioned. The subject was asked to fix the pin on the body part in the order of one point for very mild pain, two points for next maximum pain and so on up to 6 points. It is observed that the BPDS of all subjects were less when transplanting was done with vegetable transplanter. The average BPDS for Alloy steel vegetable transplanter and PVC pipe transplanter were 54.18 and 49.18 in comparison with 63.18 as in case of manual transplanting method.

Table 07. Physiological characteristics of subjects for ergonomics

study of various transplanting methods		
Sr. No.	Characteristics	Values
01	Age (Years)	25-45
02	Average Body Weight (kg)	66
03	Average Height (cm)	166
04	Resting Heart rate (beats/min.)	66-80

$$BPDS = \sum (X_i \times S_i)$$

where:

(X_i) = number of body parts falling under discomfort category i

(S_i) = discomfort score assigned to that category

(S_i) = 1 to 6, where 1 = very light discomfort and 6 = extremely heavy discomfort.

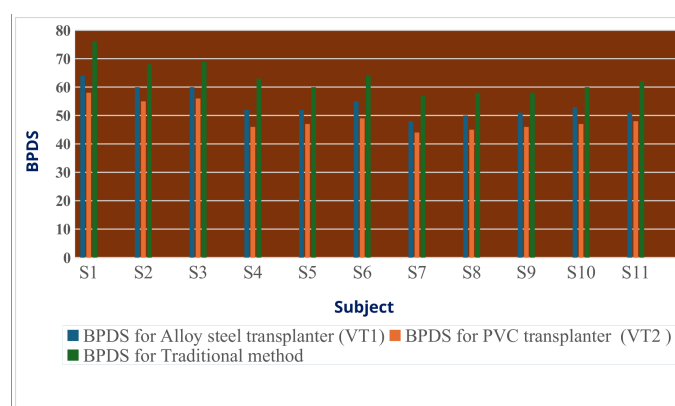


Figure 2. Body Part Discomfort Score (BPDS) in subjects/workers for different vegetable transplanting operations

Table 08. ANOVA of BPDS for various transplanting techniques

Source	SS	df	MS	F-value	p-value
Model	1107.33	2	553.667	448.919	< 0.0001
Transplanting method	1107.33	2	553.667	448.919	< 0.0001
Subject (Block)	796.242	10	79.624	64.56	< 0.0001
Error	24.667	20	1.233		
Total	1928.24	32			

The Randomized Complete Block Design (RCBD) statistical experimental design was employed with transplanting methods as various treatments and subject/worker as block. The analysis of variance through design expert software with Tukey HSD revealed that the transplanting method had a highly significant effect on body part discomfort score (BPDS) of the workers. The fitted blocked model was highly significant ($F = 448.919$, $p < 0.0001$), with an R^2 value of 0.9872 and an adjusted R^2 value of 0.9795. The mean BPDS was 54.18 for the Alloy-steel transplanter (VT₁), 49.18 for the PVC transplanter (VT₂), and 63.18 for the traditional method. Multiple comparison analysis indicated significant differences among all three transplanting methods. The PVC transplanter resulted in a 22.16% reduction in BPDS compared with the traditional method. The coefficient of variation was only 2.00%, indicating good experimental precision. These results demonstrate that the PVC transplanter provided significantly better ergonomic performance by reducing body-part discomfort compared with both the Alloy-steel transplanter and traditional transplanting method.

Overall discomfort rating (ODR)

For the assessment of overall discomfort rating, a 10-point psychophysical rating scale (0-no discomfort, 10- Extreme discomfort) was used. A scale of 70 cm length was fabricated having 0 to 10 digits marked on it equidistantly.

A movable pointer was provided to indicate the rating. At the ends of each trial subjects were asked to indicate their overall discomfort rating on the scale. Each trial of test run was longed for 1 hour. The average overall discomfort for traditional transplanting method was highest i.e. 8.17 than Alloy steel vegetable transplanter (5.8) and PVC pipe made transplanter (5.4).

Heart rate variation and energy expenditure rate

For calculation of Energy Expenditure Rate (EER) from heart rate (Varghese *et al.*, 1994) [11], the following equation was used: (Varghese *et al.*, 1994) [11]

$$EER (KJ/min) = 0.159 \times HR (\text{beats/min}) - 8.72$$

The physiological workload imposed on the subjects during transplanting was assessed in terms of average heart rate and energy expenditure rate. The measured values were compared with the established occupational workload classification proposed by Varghese *et al.* (1994) [11], and the transplanting activity was categorized according to the corresponding workload intensity. The physiological responses of the subjects were statistically analyzed using a paired *t*-test to compare the PVC-made vegetable transplanter with the conventional manual method. The mean heart rate recorded with the PVC transplanter was 104.00 ± 15.10 beats/min, whereas it was 121.09 ± 8.53 beats/min during manual transplanting. This represents a mean reduction in heart rate of 17.09 beats/min, equating to a 14.11% decrease. The difference was highly significant ($t = -6.448$, $p < 0.001$). In a similar vein, the mean energy expenditure rate was 7.816 ± 2.401 kJ/min with the PVC transplanter, compared to 10.533 ± 1.356 kJ/min during manual transplanting. The use of the PVC transplanter resulted in a reduction of 2.717 kJ/min, or approximately 25.80%, in energy expenditure. This difference was also statistically highly significant ($t = -6.448$, $p < 0.001$). The large paired effect size (Cohen's $d_z = 1.944$) further underscores a substantial reduction in physiological workload when employing the PVC vegetable transplanter. Overall, the findings indicate that the developed transplanter significantly reduced both cardiovascular strain and energy expenditure compared to conventional manual transplanting.

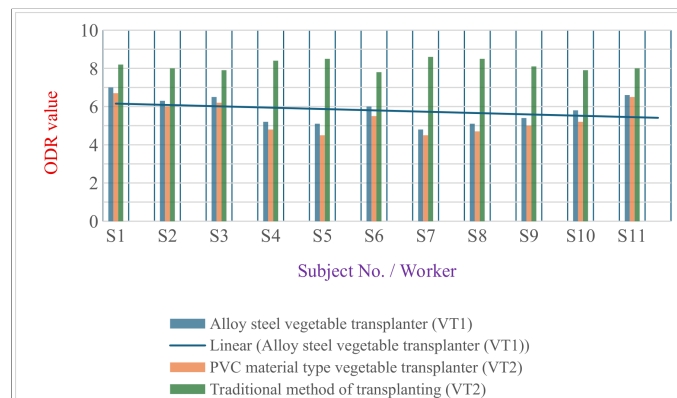


Figure 3. Overall Discomfort Score of subjects for various transplanting methods

Work load

The activity was classified as Light to moderate by using vegetable transplanter and heavy with traditional method of transplanting as the energy expenditure was reduced with developed transplanter. Farmers were comfortable while working with developed transplanter as they were relieved from back pain and standing posture added. Since the same 11 subjects performed both treatments (PVC transplanter and manual transplanting), the appropriate analysis is a paired-samples *t*-test for HR and EER.

Table 09. Heart rate and energy expenditure for different subjects

Subject No.	HR (beat / min) with PVC made vegetable transplanter	EER (KJ/min) PVC made vegetable transplanter	HR (beat / min) in manual transplanting	EER (KJ/min) in manual method of transplanting
Subject 1	85	4.795	110	8.77
Subject 2	95	6.385	114	9.406
Subject 3	117	9.883	122	10.678
Subject 4	91	5.749	110	8.77
Subject 5	82	4.318	115	9.565
Subject 6	100	7.18	116	9.724
Subject 7	99	7.021	125	11.155
Subject 8	125	11.155	131	12.109
Subject 9	111	8.929	129	11.791
Subject 10	121	10.519	134	12.586
Subject 11	118	10.042	126	11.314
Average	104	7.816	121.09	10.53

Percentage grip strength reduction

Grip strength (Kg) was measured by grip strength dynamometer before and after 1 hour of continuous work which is shown in table as follow. The grip strength of the workers decreased after conducting the vegetable transplanting operation. The average grip strength reduced from 27.86 kg before work to 25.52 kg after the operation, with an average reduction of 8.40%. This reduction indicates the development of muscular fatigue in the upper extremities due to the continuous repetitive manual activities involved in vegetable transplanting.

Conclusions

Average labour requirements for vegetable transplanters (VT_1 and VT_2) and manual transplanting were 37, 43, and 144 man-hours per hectare, respectively. The operation costs for transplanting seedlings with vegetable transplanters VT_1 , VT_2 and manual transplanting were Rs.1992, Rs. 1851 and 4516 Rs/ha, respectively. A cost saving of about 59.85% was observed over the traditional method of transplanting. The average overall discomfort for the traditional transplanting method was highest at 8.17, compared to the Alloy steel vegetable

transplanter (5.8) and the PVC pipe-made transplanter (5.4). The Body Part Discomfort Score was higher in the traditional method and lower for the vegetable transplanter. The energy expenditure rate (KJ/min) was highest in the traditional method of transplanting, whereas it was lowest with the vegetable transplanter made of PVC material, and the workload of the vegetable transplanter was categorized as moderate. The vegetable transplanter made of PVC material was ergonomically better than the vegetable transplanter made of Alloy steel. The manually operated PVC made Vegetable transplanter showed potential for transplanting plug-tray grown tomato seedlings under tested field conditions.

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