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Development and ergonomic evaluation of hand held vegetable seedling transplanter

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Abstract

Efficient vegetable production is essential to meeting growing food demands, requiring innovative solutions to reduce labor intensity and enhance productivity. Vegetable cultivation, especially for small farmers, demands innovative and affordable solutions to enhance productivity and reduce labor-intensive practices. The mechanization of agricultural processes has become increasingly important in reducing the physical strain and time-intensive nature of traditional farming operations, paving the way for innovative tools that enhance efficiency and user comfort. Transplanting of seedlings, a highly drudgery-oriented operation, is mainly performed by women. A hand held seedling transplanter has been designed and developed for transplanting vegetables seedlings based on the anthropometric dimensions of the user population. The number of seedlings transplanted per min using the handheld seedling transplanter ranged from 19 to 21, compared to 16 to18 using the conventional method. By using the hand held seedling transplanter, a significant reduction in the cost of operation was achieved, with 11.44 to 16.52% savings in cost reported. The average working heart rate while transplanting using the seedling transplanter was 103 bpm, compared to 120 bpm for conventional transplanting. The average energy expenditure while transplanting the seedlings using the seedling transplanter was 7.72 kJ min^{-1}, compared to 10.94 kJ min^{-1}. The performance evaluation of the designed transplanted indicted an increase in human productivity and a decrease in musculoskeletal discomfort during the transplanting process. The introduction of ergonomic and cost-effective solutions, such as the handheld seedling transplanter, not only improves productivity and reduces operational costs but also promotes sustainable practices while prioritizing the well-being of farmers.

Keywords

ergonomics; farm women; musculoskeletal discomforts; seedling transplanter; surface electromyography; transplanting

Introduction

In recent years, there has been a shift in cropping pattern towards horticulture. Seedling transplanting operation is performed manually and account for 40% of total working hours of cultivation (1). The labour requirement in manual transplanting of vegetable seedlings varies from 120-420 man h ha^{-1} (2, 3). Presently, most of the operations under vegetable cultivation are accomplished manually. These operations are typically performed while kneeling, or squatting posture.

Therefore, they are more tedious, uncomfortable, tiresome and drudgery prone (4). Since many Indian farmers are having small land holdings, they are unable to procure costly machinery for vegetable cultivation. The current need in vegetable farming, particularly in seedling transplanting, is the development of affordable, ergonomic technologies that can effectively address the limitations of traditional cultivation practices. This is especially critical for small landholding farmers, who often lack access to cost-effective and user-friendly solutions tailored to their specific needs.

Seedling transplanting plays a crucial role in vegetable cultivation as it ensures better crop establishment, uniformity and higher yields. However, farm women often face challenges such as physical strain, long working hours and limited access to efficient tools, which can lead to musculoskeletal injuries and decreased productivity. Several studies conducted among farm women in India reveal that majority of the farm women have experienced one form or other type of musculoskeletal discomforts (5-7) during different agricultural activities. Thus, it is imperative to design region specific agricultural tools which can be used by the women to perform the agricultural operations. Mechanizing the transplanting process can significantly reduce labour intensity, enhance precision and improve overall efficiency, offering potential benefits such as increased yield, reduced health risks and greater empowerment for farm women. This shift towards mechanization could also contribute to more sustainable and profitable farming practices. Hence, a hand held seedling transplanter has been designed, developed and evaluated based on the field performance and ergonomical parameters with an objective to reduce the drudgery of farm women in the vegetable seedling transplanting operation. The evaluation was performed through estimating field efficiency and labour savings.

Materials and Methods

The methodology adopted for the present study includes the design, development and performance evaluation of the designed transplanter and its ergonomic parameters.

Design of hand held seedling transplanter

The height of the transplanter was designed as 110 cm based on the average elbow height of women (8). The hand held seedling transplanter has been provided with two handles which aids in easy lifting while operating the tool.

Seedling delivery tube: The delivery tube was designed and made using two different materials. Both ends of the seedling delivery tube were made up of mild steel, while the middle portion of the seedling delivery tube was made up of transparent acrylic pipe. Mild steel was selected to offer strength at the ends, which is experiencing frequent loads. Acrylic material which was transparent and lighter in weight for visibility of seedlings flow and reduction in weight.

Height of the handle from the ground: The height of the handle of the transplanter from the ground should be designed in such a way that during operation the operator stands erect as far as possible to reduce musculoskeletal discomfort (9). Taking elbow flexion angle as 101.6° for the users, the height of the handle was determined as 90 cm based on user's population (10).

Size of the jaw mouth: The length of the jaw was designed as 130 cm so that the seedling could be placed up to a depth of 5 cm in the soil. The apex angle of the jaw and jaw opener has been designed considering the angle of penetration.

Development and performance evaluation of the designed transplanter

Performance evaluation of the designed transplanter was carried out as per the guidelines suggested for testing and evaluation of agricultural machinery and evaluation suggested by FAO Agricultural Services Bulletin (11). Seedlings of the brinjal crop were used for transplanting using the developed tool. Brinjal seedlings were selected out of the various vegetable seedlings, based on the wider prevalence of cultivation in the locality. The efficiency of the tool was tested in 0.1 ha area for each method i.e. conventional and by using hand held seedling transplanter. The brinjal seedlings of 18-25 days old raised in portrays were used. Average seedling height was around 150 mm. The design adopted for the present study is Randomised Block Design (RBD). The design of study is presented in Table 1.

Table 1. Design of study for the evaluation of seedling transplanter

Sl. No.	Treatment	Levels
1.	Vegetable	A1- Brinjal
2.	Transplanting	B1 – Conventional method
		B2 – hand held transplanting tool method
3.	Subjects	6 (S1-S6)
4.	No. of Replications	3
5.	No. of experiments	2x6x3 = 36

Field evaluation of seedling transplanter

Seedlings delivered: The seedlings delivered per min was calculated by observing the average time required for transplanting seedlings in seconds using the following formula (Eq 1).

$$\text{Seedling delivered, min}^{-1} = \frac{60}{t} \qquad \text{Eq 1}$$

where,

t = average time required for transplanting one seedling, (s)

Speed: The speed of transplanting operation of hand held transplanter was determined by the following formula (Eq 2) for a plant to plant spacing of 45 cm.

$$\text{Speed, km h}^{-1} = \frac{0.45}{t \times 3.6} \qquad \text{Eq 2}$$

where,

t = average time required for transplanting one seedling, (s)

Theoretical field c-apacity: The actual field capacity of the transplanter was calculated by the following formula (Eq 3).

$$\text{Theoretical field capacity, ha ha}^{-1} = (NxWxS)/10 \qquad \text{Eq 3}$$

Where,

N = Number of rows in single pass

W = Distance between two rows, m

S = Speed of operation, km h^{-1}

Actual field capacity was calculated from the actual field area covered (ha^{-1}) in the unit time (h^{-1}) from the field observation.

Field efficiency**:** Field efficiency of the transplanter in percentage was calculated by taking the ratio of actual field capacity to theoretical field capacity of the transplanter. The theoretical speed of operation was considered as 0.7 km h^{-1}.

Labour requirement: Labour required was calculated in terms of the man hours required for transplanting in one hectare area by taking inverse of actual field capacity.

Cost of operation: The labour charges were considered as Rs. 25 h^{-1}. Hence the labour cost required (Rs.) for one hectare transplanting was calculated by multiplying man hours required for transplanting in one hectare area with 25.

Saving in cost and time: The performance parameters were measured and compared with the transplanting operation using manual method and developed hand held vegetable transplanter. It is calculated (12) by the ratio of labour requirement in traditional method minus labour requirement in transplanter to labour requirement in machine method of vegetable transplantation and it is expressed in percentage.

$$\text{Labour saving over manual method (\%)} = \frac{L_1 - L_2}{L_2} \times 100 \quad \text{Eq 4}$$

Where,

L_1=Cost incurred in conventional transplanting, Rs ha^{-1}

L_2=cost incurred in manual transplanter, Rs ha^{-1}

$$\text{Time saving over manual method (\%)} = \frac{T_1 - T_2}{T_2} \times 100 \quad \text{Eq 5}$$

Where,

T_1 = Time required in conventional transplanting, h ha^{-1}

T_2 =Time required in manual transplanter, h ha^{-1}

Selection of subjects

Six farm women who were free from any ailments and willing to participate in the study were selected by adopting purposive sampling method. The purposive sampling method was selected, since the workers engaged in transplanting process were purposively selected to observe the user-based evaluation. They were given training on use of seedling transplanter for a week. Once they were familiar with the operation, they had to perform both methods of transplanting on the same day for about an hour for each method. Sufficient rest was given for the farm women. They were randomly assigned the method of transplanting and the same method was adopted for the three replications.

Ergonomic evaluation - Measurement of heart rate

Portable HR monitor (Polar V 800) was used to measure the heart rate. The experiment was carried out after recording the Resting Heart Rate (RHR) and thereafter Working Heart Rate (WHR). On completion of the transplanting the Recovery Heart Rate was recorded.

Measurement of body part discomfort score (BPDS)

Corlett and Bishop technique (13) was used to measure body part discomfort score (BPDS) Fig.1. The discomfort was ranked on five -point scale with extreme discomfort (6) to no discomfort (2).

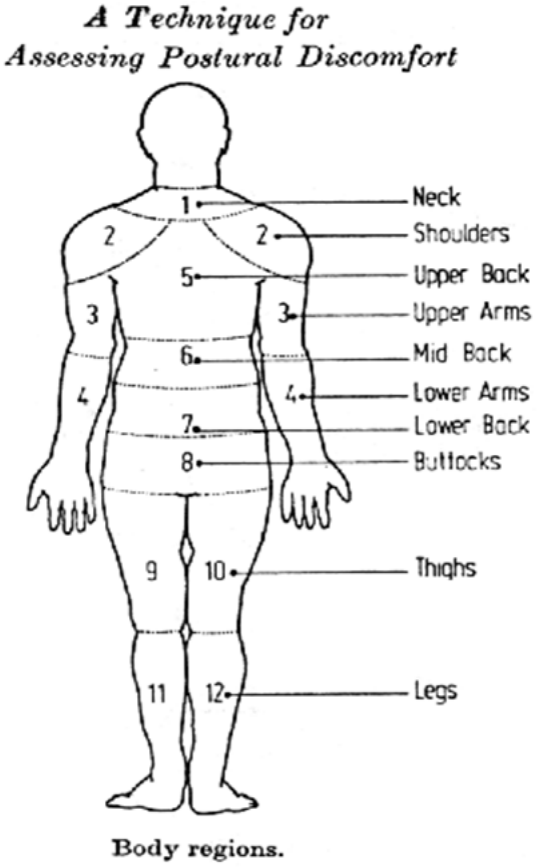

Fig. 1. Body map showing different body parts (BPDS).

Analysis of data

The data obtained from the field experiments were analysed using the statistical software SPSS 20.0. ANOVA and paired t test were performed in this study.

Results

Design and development of hand held seedling transplanter

A hand held seedling transplanting tool was designed and developed for transplanting the seedlings of vegetable crop. The complete design specification of the hand held seedling transplanter is listed in Table 2. The design drawing of the hand-held seedling transplanter is show in Fig. 2.

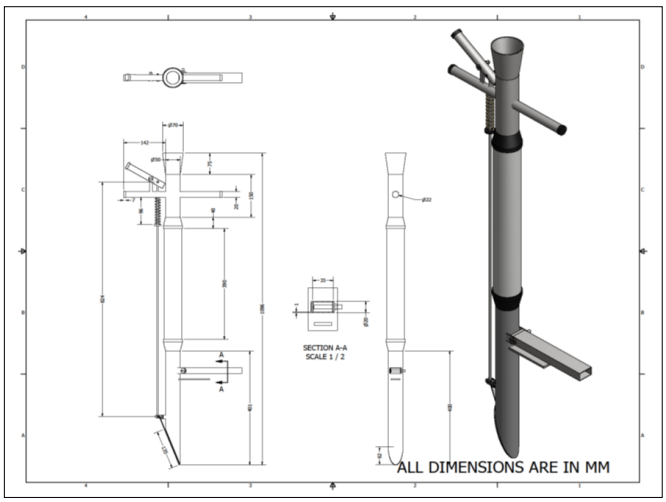

Fig. 2. Design drawing of hand held seedling transplanter.

Table 2. Specifications of hand held seedling transplanter

Sl. No	Features	Unit	Specifications	Remarks
1	Weight of the tool	Kg	1.65	Light weight and easy to transplant seedlings
2	Height of the transplanter	mm	1096	Made up of transparent acrylic pipe with 3 mm thickness which aids in weight reduction. Designed based on the elbow height of women (5th percentile- 896 mm)
3	Height of the handle from ground	mm	900	The handle was made up of stainless steel. Aids to hold the tool and operate the lever on opening of the jaw.
4	Length of the handle in left side	mm	115	Designed based on the hand breadth of women (95th percentile- 81mm) with clearances on either side of the handle.
5	Length of the handle in right side	mm	160	Designed based on the hand breadth of women (95th percentile- 81 mm) with clearances to operate the lever mechanism.
6	Diameter of handle	mm	20	Designed based on the easyness of use by the farm women
7	Diameter of Seedling hopper	mm	65	Funnel shaped hopper was designed for easy flow of the seedlings aged between 18-25 days and the diameter was designed based on the floral spread of the seedlings.
8	Type of clutch used	-	Lid with lever mechanism	A lid at the end of the vertical tube has a sharp end which can be pushed easily into the soil.
9	Length of the jaw	mm	130	Penetrates into the soil by 5 cm depth to facilitate easy pressing.
10	Apex angle of the jaw	deg	37	Designed for the appropriate penetration of the tool into the soil.
11	Length of the lever	mm	690	The lever was made up of stainless steel material and the thickness of the lever is 5 mm. This lever enables the movement of jaw opening while the lever is pressed against the handle.
12	Spacing marker	mm	300 to 450	The spacing marker is adjustable according to the requirement of the crop. The marker is used for planting accuracy in inter row spacing and intra row spacing of seedling in the field.

Physiological characteristics of the subject

The details of the selected subjects involved in the ergonomic study are presented in Table 3. All the selected subjects had more than ten years of experience in farming activity and their age ranged from 37 to 47 years. The height, weight was recorded to arrive at Body Mass Index (BMI).

Table 3. Physiological characteristics of the subjects

Subjects	Age (years)	Body weight (kg)	Height (cm)	BMI (kg/m^2)
S_1	37	47	157	19.07
S_2	40	52	161	20.06
S_3	35	51	155	21.23
S_4	46	43	152	18.61
S_5	36	54	160	21.09
S_6	47	62	157	25.15

Parameters of brinjal seedling

Table 4 presents the seedling parameters of the selected vegetable crop. The age of the selected seedling was between 18 -25 days with a leaf stage of 2-4 leaves. The mean height of seedling was 10.2 cm with a floral spread of 6.4 cm. The row to row spacing was 60 m with plant to plant spacing of 45 cm. The field photograph of the seedling transplanting operation is shown in Fig. 3.

Table 4. Parameters of brinjal seedlings

Parameter	Seedling
Age of the seedling (days)	18-25
Leaf stage	2-4
Floral spread (cm)	6.4
Mean seedling height (cm)	10.2
Row to row distance (cm)	60
Plant to plant distance (cm)	45
Variety of vegetable	Disco

Fig. 3. Transplanting using hand held seedling transplanter.

Effect of transplanting method on time and survival of seedlings

Table 5 represents the effect of the transplanting method on time and survival rate of the seedlings. The time taken to complete a 10 m ridge in both conventional method and by using the seedling transplanter were recorded and it was1.42 min as against 1.11 min for transplanting. There was a highly significant reduction ($P< 0.01$) in the time taken to cover a 10 m ridge while transplanting using the seedling transplanter.

The percentage of survival while using the hand held seedling transplanter was 90.5 and while transplanting in conventional method was 94.11. No significant variation was observed between the conventional method and the hand held vegetable transplanter method.

Table 5. Effect of transplanting method on time and survival of seedlings

Parameters	Conventional method	Hand held seedling transplanter	Value
Time# (min)	1.42	1.11	7.512**
Survival## (%)	94.11	90.58	1.746^{NS}

#Time taken to complete 10m ridge; ##Percentage of survival /10m ridge; **P <0.01, NSP <0.05

Physiological parameters of the subjects during transplanting process

The physiological parameters of the subjects are presented in Table 6. The average working heart rate while transplanting using the seedling transplanter was 103 bts min^{-1} and it was 120 bts min^{-1} for conventional transplanting. The average energy expenditure while transplanting by conventional method and by usings seedling transplanter were determined as 10.94 kJ min^{-1} and 7.72 kJ min^{-1}. The workload of the subjects was derived based on the classification of workload (14).

Field performance parameters of the seedling transplanting methods

Fig. 4 depicts the field performance parameters of the hand held seedling transplanter compared to the conventional method. The number of seedlings transplanted per min using the hand held seedling transplanter ranged from 19-21 as against 16-18 with the conventional method. The actual field capacity values varied from 0.020 to 0.026 ha h^{-1}. Specifically, the actual field capacity was 0.02 ha h^{-1} for conventional method, while it was 0.026 ha h^{-1}. using the hand held seedling transplanter. The field efficiency percentage was 80.19% for the hand held seedling transplanter. A 35% reduction in the labour requirement was recorded for using the hand held seedling transplanter.

The cost of seedling transplanting operation ranged between Rs. 1002.3 $ha^{-1}$to Rs. 1017.83 ha^{-1} for transplanting using the hand held seedling transplanter. The cost of operation for transplanting the seedlings by the conventional method ranged from Rs. 1168.36 to Rs. 1238.28 ha^{-1}. The cost of transplanting seedlings with the hand held seedling transplanter ranged from 11.44 to 16.52%. Similarly, savings in time was observed ranging between 15.10 to 19.90%. Performance evaluation of the seedling transplanter indicated that the field capacity of the designed transplanter was 0.026. The results are in line with the field capacity of the seedling transplanter developed by (14) which ranged from 0.021 to 0.034 ha h^{-1}. Few low cost hand held vegetable transplanters were developed with a field capacity of about 0.02 ha h^{-1} and field efficiency of 82.3% (15) and transplanting rate of 15 - 17 seedling per min (2). The mean cost of operation was Rs. 1308.16 ha^{-1} as against Rs. 1032 ha^{-1}.

Table 6. Physiological parameters of the subjects during transplanting process

Subjects	Conventional method			Hand held seedling transplanter			Paired t-test	
	HR (bts/min)	Energy expenditure (kJ min^{-1})	Work load	HR (bts/min)	Energy expenditure (kJ min^{-1})	Work load	HR (bts/min)	Energy expenditure (kJ min^{-1})
S_1	125	11.16	H	112	9.09	M	5.642**	2.735*
S_2	121	10.52	H	105	7.98	L		
S_3	115	9.57	M	87	5.11	VL		
S_4	124	11.00	H	107	8.29	M		
S_5	119	11.54	M	106	7.76	M		
S_6	121	11.87	H	103	8.12	M		

*p<0.05, **p<0.01, NS

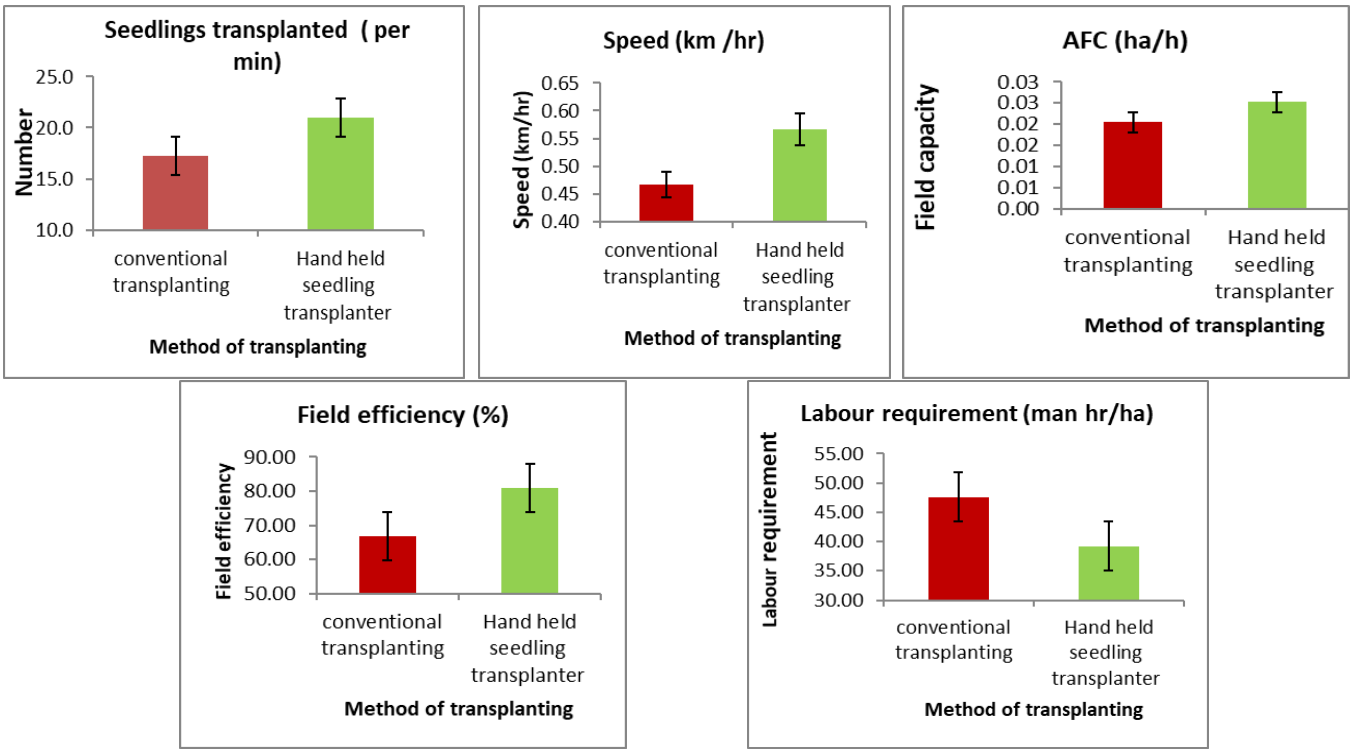

Fig. 4. Various field performance parameters of the seedling transplanting methods.

Musculoskeletal discomfort of farm women during transplanting of seedlings

Table 7 shows the musculoskeletal discomfort rating observed for the women subject while transplanting by conventional method and hand held seedling transplanter method. It was observed from the that the mean values of the discomfort ratings were higher lower back (4.562±1.03), lower legs (3.81±1.37) and hip region (3.625±1.2) during conventional method of transplanting. During the transplanting by hand held seedling transplanter method, highly significant reduction (P<0.01) in the discomfort rating in the lower back (1.625±0.62), upper back (1.182±0.4), neck (1.5±0.51), shoulder (1.812±0.75), elbow (1.25±0.44) and lower arm (1.25±0.57). The reduction in the discomfort rating was due to the change of posture from bending to standing, which had resulted in increase in productivity of the farm women (Fig. 5). Reducing musculoskeletal discomfort in farm women can lead to long-term benefits such as improved physical health and productivity, enabling them to perform tasks more efficiently. Additionally, it lowers healthcare costs by minimizing the risk of chronic conditions and injuries associated with repetitive or strenuous farm activities.

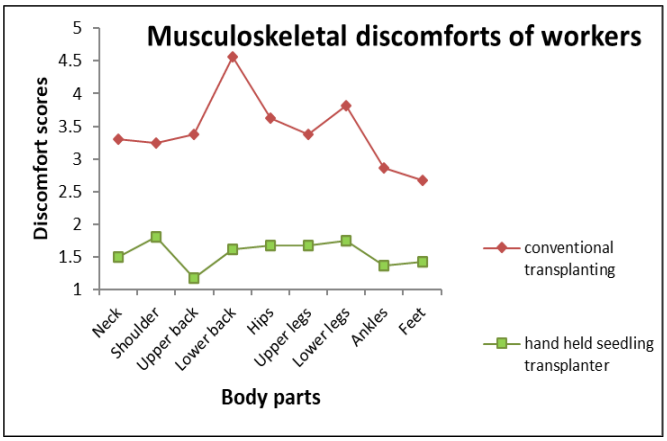

Fig. 5. Musculoskeletal discomforts of workers.

Conclusion

The role of women in agriculture and allied activities has been well documented by several researchers across the globe. Farm mechanisation, being a primary focus of agricultural research, has emphasized the development of low cost, region specific and gender friendly tools for various agricultural operations. Hence, an attempt has been made to design and develop a hand held seedling transplanter which is more suitable for small and marginal farms to transplant vegetable seedlings. Performance evaluation of the designed transplanter has been carried out among the farm women and the results indicated that there was an increase in human productivity and decrease in musculoskeletal discomforts during the transplanting process using the hand held seedling transplanter. By integrating these ergonomic solutions into vegetable farming, it can contribute to enhanced productivity, greater sustainability and reduced healthcare expenditures on a global scale, benefiting not just farm women but all labourers involved in agriculture.

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Authors' contributions

PKP involved in investigation, design and writing of the manuscript. PP and ST involved in data analysis and validation. BN and TA involved in experimentation and manuscript editing.

Compliance with ethical standards

Conflict of interest: Authors declare that there is no conflict interest exists

Ethical issues: None

Table 7. Musculoskeletal discomfort of farm women during transplanting of seedlings

S.No	Body Parts	Musculoskeletal discomforts		Paired t-test value
		Conventional method	Hand held seedling transplanter	
1.	Neck	3.31±1.25	1.50±0.51	6.926**
2.	Shoulder	3.25±0.93	1.81±0.75	7.064**
3.	Upper arm	2.50±1.09	2.12±0.62	1.145^{NS}
4.	Elbow	2.06±0.93	1.25±0.44	3.569**
5.	Lower arm	2.37±1.41	1.25±0.57	2.915**
6.	Wrist	2.43±0.96	2.18±0.75	1.291^{NS}
7.	Palm	2.18±1.16	1.93±0.77	1.291^{NS}
8.	Fingers	3.31±1.57	1.56±0.51	4.583*
9.	Chest	1.68±0.60	1.37±0.62	1.576^{NS}
10.	Abdomen	1.50±0.63	1.18±0.40	2.076*
11.	Upper back	3.37±1.54	1.18±0.40	5.202**
12.	Lower back	4.56±1.03	1.62±0.62	10.457**
13.	Hips	3.62±1.2	1.68±0.70	5.783**
14.	Upper legs	3.37±1.45	1.68±0.71	3.967**
15.	Lower legs	3.81±1.37	1.75±0.77	5.567**
16.	Ankles	2.87±1.54	1.37±0.71	3.426**
17.	Feet	2.68±1.19	1.43±0.51	3.596**

** p<0.01 at 99% confidence interval ,* p<0.05 at 95% confidence interval, ns non significant

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