Research Article

DEVELOPMENT OF A GRIPPER FOR ROBOTIC PICKING AND TRANSPLANTING OPERATION OF PROTRAY GROWN VEGETABLE SEEDLINGS

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ABSTRACT

The existing system of vegetable cultivation is to transplant the seedling manually with the help of labours. The labour requirement in manual transplanting of vegetable seedlings is as high as 254 man–h ha^{-1}. However, seedling transplanting, as a labor-intensive task. The main objective of this study was to develop an efficient mechanical linkage pick-up device. To develop an experimental setup of automatic picking and transplanting mechanism for plug type vegetable protray seedlings and evaluate its performance under laboratory condition.Sliding plate cam type mechanical linkage finger was developed and tested with experimental setup. The experimental setup was consisted of a main frame, aluminium extrusion, linear guide rail, limit switch, stepper motor with pulleys, timer belt, pneumatic cylinders, solenoid values with coils, FRL unit, SMPS, PLC board, relay board and conveyor. The four symmetrically arranged prongs were actuated by pneumatic cylinder to achieve opening and closing of gripper device. There was another pneumatic cylinder, which plug out the seedling from protray cell. PLC programming was used to control the entire operations of transplanting mechanism. The transplanting rate was set as 840-850 seedlings h^{-1}. The level of variables *Viz.*, age of seedlings (20, 25 & 30 days for tomato & for chilli and brinjal seedlings 30, 35 and 40 days seedlings), media moisture content (16%, 18% and 21%)and penetration angle(6°, 8° and 10°)were taken for the study.The maximum success ratio of 90.69 % were found with optimum levels of (moisture content and penetration angle) 19 ±1 % and 8° respectively. About 3.07 % of missing, 2.44 % of damage to the media and or seedlings and 1.39 % of drooping failure was recorded with 25 days aged seedlings. Similarly, for chilli and brinjal, the maximum success ratio of 92.47 % and 91.32 % respectively were found at the same levels with 40 days aged seedlings. Also about 2.61 % of missing, 2.08 % of damage to the media and or seedlings and 2.43 % drooping failures were found for chilli seedlings and about 2.82 % of missing, 3.16 % of damage to the media and or brinjal seedlings and 2.11 % of drooping failures were found for brinjal seedlings.

INTRODUCTION

India is the second largest producer of vegetables next to china in the world. In India, it is grown in an area of 9.575 million hectares with the productivity of 17.7 mt ha^{-1} which contributes 14% of the total world production of vegetables. Vegetable production in India is 176 million tonne in 2016-17. Tomato, chilli, brinjal and cauliflower is a most widely grown vegetable crops in India. The total area of tomato cultivated in India is currently 8.08 lakh hectare yielding 196.96 lakh metric tonne. (Source: Ministry of Agriculture & Farmers Welfare, Govt. of India).

All farm operations except seedbed preparation are carried out by manually. The existing system of vegetable cultivation is to transplant the seedling manually with the help of women labours (Zhou *et al.*, 2009). The labour requirement in manual transplanting of vegetable seedlings is as high as 253 man–h ha^{-1} for tomato transplanting, 254 man-h ha^{-1} for chilli transplanting and 184 man-h ha^{-1} for brinjal transplanting (Garg and Dixit, 2002).However, seedling transplanting, as a labor-intensive task. With the shortage in skilled labor and increasing labor cost, it is urgent for India and other developing countries to develop an automatic transplanter with simple structure, high operation accuracy, and economically feasible for local transplanting production (Parish, 2005; Kumar *et al.,* 2008).

Research on the development of an automatic transplanter for plug type vegetable seedlings began several years ago. In view of this, Xin *et al.* (2018) designed and implemented an intelligent transplanting system based on photoelectric sensor and PLC. The system was tested by using pepper seedlings and resulted the rate of success seedling picking was 88.23 per cent.Tian and Qiu (2011) described a simple and practical automatic transplanter for flower seedlings which was reported to have worked quite well. Han *et al.* (2018) developed multi-task robotic transplanting work cell for greenhouse seedlings.

These transplanting systems were performed well, but their complex structure and high manufacturing costs have made it difficult to be used by a large number of growers. In addition, these transplanting system are not feasible for local plug transplants production since publication of their designs do not match progress made so far in the agronomic technology of seedling production. All these above said automatic transplanting systems were developed and tested greenhouse at different countries. However, the fully automated transplanting system for plug type vegetable seedlings nowhere developed in India so for.

Kavitha and Duraisamy (2007) developed a tractor operated three row semi-automatic vegetable transplanter for tomato, chilli and brinjal. Three persons need to sit and feed the seedlings continuously in the holes, which is a tiresome process for transplanting larger area. It has a limited operating speed due to the need for manual feeding of seedlings one by one. It is not suitable for continuous operation over a long period of time.

Sivakumar and Durairaj (2014) developed a gravity fed automatic vegetable transplanter. The main objective of this work was to drop the seedling by gravity without causing damage to the seedling. To make the feeding protray simple, an open bottom type pro tray seedling was used. To move the tray continuously, a 50-rpm gear motor with finger type moving mechanism was developed and tested. Under laboratory condition, it was found that it was feasible to drop 28 plants min^{-1}. Even though it is automatic transplanter, the transplanting system has some disadvantage. It is very difficult to make the hole at the bottom of every cell in entire protray at each time. Farmers may not be equipped to make the hole at the bottom of every cell in entire protray at the time of seedlings growing.

Despite some of these attempts, fully automated transplanting has not seen much success and popularization in India. The main objective of this study was to develop an efficient mechanical linkage pick-up device. To develop an experimental setup of automatic picking and transplanting mechanism for plug type vegetable protray seedlings and evaluate its performance under laboratory condition.

MATERIALS AND METHODS

Nursery grown vegetable seedlings

Vegetable seedlings nursery growing pattern is a most important factor in developing of automatic transplanting mechanism. Vegetable seedlings have been traditionally grown on soil beds in open field for a long period. Compared to traditional nursery beds, seedlings that are raised using portray germinate early and are vigorous. There is good root development in the seedling. Low mortality rates of the seed is observed that are sown in portray (Bhardwaj, 2014). Different shapes and sizes of protrays are available at commercially. Vegetable growers are commonly practicing 98 cells and or 221 cells protray. Taking tomato, chilli and brinjal seedlings production in the 98-cell protrays as transplanting object, seeds were sown per cell containing 17.83 cm^3 of substrates and fine coir pith used as a growth media. The final mean growth characteristics of vegetable protraygrown seedlings as related to transplanting are presented in Table 1. Measurement of growth characteristics of vegetable protraygrown seedlings are shown in Fig. 1.

Table 1. Growth characteristics of vegetable protray grown seedlings

SL. No.	Vegetable seedlings	Shoot length	Root length	Stem diameter	Number of leaves	Pulling force
1	Tomato	96.00	58.89	1.66	6	1.02
2	Chilli	167.58	96.89	1.93	7	1.23
3	Brinjal	140.07	85.69	2.45	7	1.47

Development of a robotic pick-up and transplanting unit are shown in Fig. 2. It is a gantry structure robotic mechanism consisting of a main frame, aluminium extrusion, linear guide rail, limit switch, stepper motor with pulleys, timer belt, pneumatic cylinders, solenoid values with coils, Filter Regulator Lubricator (FRL) unit, Switched Mode Power Supply (SMPS), Programmable Logic Controller (PLC) board, relay board and conveyor. All other components were mounted on mild steel mainframe. The entire gripping unit was mounted on aluminum extrusion. The linear guide rail was designed to move the gripping unit along an appropriate path from the source protray cells of each row to the destination location. The function of the gripper is to grasp, hold, and release a protray seedling.

Fig. 1. Measurement of growth characteristics of vegetable protray grown seedlings development of a robotic pick-up device

Fig. 2. Development of a robotic pick-up and transplanting unit

The prong fingers were of 185 mm length and made of 2.5mm diameter spring steel. The upper end of the prong was pivoted to the central hub attached to the picking cylinder. The gripping and ejection of the seedlings was done by a separate cylinder. The picking cylinder implements the picking action and the removal of the seedling from the protray cavity. This cylinder is mounted on linear guide and a 5A stepper motor drives the carriage. A PLC with microcontroller was used to control the stepper motor to position the picking cylinder just above the protray cavity. Control unit of the entire transplanting system is shown in Fig.3. The transplanting rate was set as 840-850 seedlings h^{-1}.

Gripper tower

Two pneumatic cylinders were used to grasp and remove the plug type seedling from protray cell. The function of gripper was actuated by pneumatic cylinder which stroke length was 60mm. Another pneumatic cylinder, which stroke length of 50mm, was used to plug out the seedling from protray cell. Seedling ejection pneumatic cylinder was mounted on the linear guide rail with the help of 'L' bracket, which made up of mild steel. Cylinder shaft was threaded hexagonal nut and pneumatic cylinder was clamp hexagonal nut, which the stroke length of 60mm. Pneumatic cylinder was directly threaded with gripper head, which made up of stainless steel.

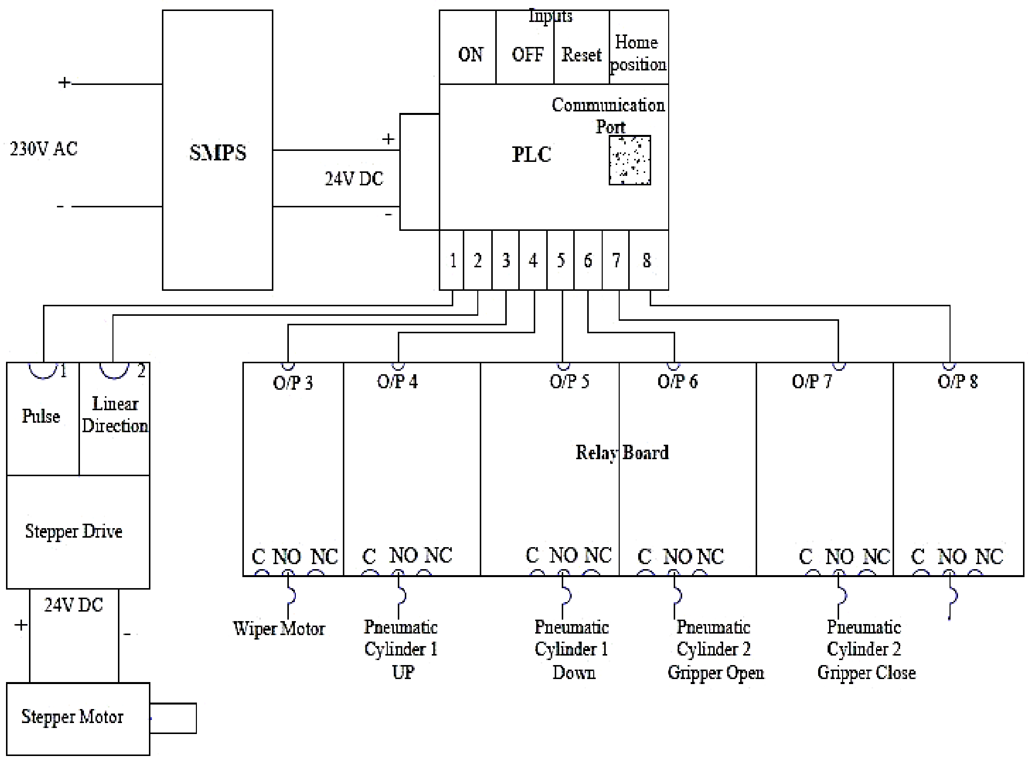

Fig. 3. Control unit of the vegetable seedling transplanting system

Protray conveying mechanism

A belt conveyer was used for the automatic movement of protray at a regular interval. A 45 rpm wiper motor was used for the operation of the conveyor. A solid state relay of no.7 was used for the rotation of the wiper motor. The entire system was controlled by PLC programming. After the complete removal of seedlings from the first row of the protray, the conveyor moves one step forward to position the cells of the second row of the protray just below the gripper mechanism. The distance of movement of tray and the time taken for the movement were measured and it was incorporated in the programme.

Optimum test design

The main purpose of these laboratory experiments was to determine the effect of influencing variables on the successfully grasping, removing and realising of the plug from the protray as plugged out from the cell. The three selected independent variables were age of vegetable seedlings, growth media moisture content and penetration angle. Conventionally, the farmers practise transplanting of 25 days old for tomato plug seedling. However, it was planned to test 20 and 30 days old seedlings also, since the seedlings would be easier to eject if the root mass formed is solid by age. Hence, the three levels planned were 20, 25 and 30 days (A) old seedlings.

Media moisture content is one of the most important parameter that which influencing the success or failure of plug seedlings. Yang *et al.* (1991) and Ryu *et al.* (2001) indicated that there might be an optimum range of media moisture content (M), which would facilitate the extraction of seedlings. Therefore, the media moisture conditions were strictly examined in this study. The levels of media moisture content were fixed as per method followed by Yang *et al.* (1991) and Ryu *et al.* (2001) and it was 16, 18 and 21 per cent.

In addition, the penetration angle (θ) must be less than the tray cell taper (Mao *et al.*, 2014). Yang *et al.* (1991) specified that, when the growth medium is loosely filled soil mix (as opposed to a fibrous cube such as rock wool), the root system is a major component for bearing force while the seedlings are lifted. Therefore, it is important to insure that the needles grasp the maximum amount of root mass. For this reason, the positioning of the needle relative to the root cell is critical. The relative positions of the needle-tips can be determined by the angles of the needlesduring the grasping action. A study was conducted on the effect of different angles (6°, 8°, and 10°) of the gripper needles on the percentage of successful picking and dropping.

The success of ejection or failure was recorded in each replication. The corresponding data was recorded and statistical analysis was carried out with AGRESS software. A completely randomized design of statistical experiment was planned, wherein the response variable is a success or failure over the three independent variables. The results were expected to optimize the variables to achieve maximum picking and dropping of protray grown vegetable seedlings.

Performance test design

To evaluate the performance of developed automatic picking and transplanting mechanism, the tests were conducted at laboratory condition. The tests could also be used to evaluate the practicality and adaptability of the robotic pick-up device. Experiment were conducted in two numbers of 98 celled portrays for each crop viz., tomato, chilli and brinjal and the transplanting rate was set on an average of 840-850 seedlings h^{-1}. Each test was repeated three times.

Success ratio

In the test trials, extraction failure, delivering failures and breakage of root lump were considered as functional failures. Since the leaf damage had little effects on vegetable growth after transplanting (Choi *et al.,* 2002), the stems torn by the pins were considered as seedling damages. Considering these factors, a success rate (SR) in picking up seedlings was defined and calculated as follows:

$$SR\ (\%) = \frac{NSF - NFF - NSD}{NSF} \times 100 \qquad \text{-------- } \mathbf{(1)}$$

Where,

SR	:	Success Rate, per cent
NSF	:	No. of seedling fed
NFF	:	Functional failure
NSD	:	No. of seedling damage

Functional failure

The seedling functional failure was calculated by using the following formula (Kavitha, 2007)

$$NFF\ (\%) = \frac{\text{Number of seedling extraction failure}}{\text{Number of seedling fed}} \times 100 \qquad \text{-------- } \mathbf{(2)}$$

Seedling damage

The damage of the seedling plug or media during picking from the protray by the gripper was measured by using the following formula (Kavitha, 2007).

$$SR\ (\%) = \frac{\text{Number of seedling damaged while picking} \times 100}{\text{Number of seedling fed}} \times 100 \qquad \text{-------- } \mathbf{(3)}$$

RESULTS AND DISCUSSION

Optimum test

The statistical analysis are shown in Table 2, 3 and 4.The statistical analysis of variance (ANOVA) further exhibited that the seedlings age, media moisture content and penetration angle had a significant effect ($p<0.01$) on a success rate of robotic gripping device. The treatment interactions also had a significant effect ($p<0.01$) on success rate of automatic picking device. The factors, which may affect the success rate of functioning with the gripper, fall into two categories *Viz.*, nursery growing factors and mechanical factors.

Effect of age of vegetable plug type protray seedlings on success ratio

The testing results for each seedling age were compared. The success ratios were 90.69 92.47 and 91.32 per cent for 25-day tomato seedlings and for 35-day chilli and brinjal seedlings, respectively. It was found that most extraction failures occurred with younger and older seedlings because the root media of younger seedlings were not well developed. Meanwhile, the older seedlings were plump with leafy splendor making leaves often tangled with the prongs. In fact, a suitable seedling age for mechanized transplanting exists (Ryu *et al.*, 2001 and Parish, 2005). At a certain growth stage, the seedlings were both short and sturdy with a well-developed root system. These conditions are favorable for picking up seedlings from protray cell using the prongs to penetrate the growth media. However, different crops with different seedling ages should be treated differently.

Table 2. Analysis of variance for success rate of automatic transplanting mechanism with tomato seedlings

Source	df	SS	MS	F	PROB
Treatment	26	3672.46	141.24	108.63	0.034 **
Err	54	70.21	1.30	1.00	
Age of seedlings (A)	2	2309.29	1154.64	888.01	0.000 **
Media moisture content (M)	2	42.88	21.42	16.49	0.000 **
Penetration angle (P)	2	752.12	376.06	289.22	0.000 **
AM	4	226.58	56.64	43.56	0.000 **
MP	4	19.88	4.97	3.828	0.008 **
AP	4	221.85	55.46	42.65	0.000 **
AMP	8	99.83	12.47	9.59	0.052 **

C.V. (Treatment): 1.95%

Effect of media moisture content on success ratio

In the nursery growing factors, the media moisture content and age of seedlings had the highest effect on the picking efficiency of gripper. When the media moisture content is too low, the cohesive forces among the particles in the substrates, and among the substrate and the root system, decrease. As a result, the substrate in which the seedlings grow becomes loose, making the root lump easy to be crushed. In some cases, moistening the growth media may reduce the adhesion between the media and the cell walls (Yang *et al.*, 1991). On the other hand, wet root lumps are often quite soft which could make it difficult for the end-effect or to grasp the seedlings and hold the growth media of the seedling firmly (Han *et al.*, 2013). Therefore, under and more growth media moisture content is not suitable for automatic transplanting mechanism. Within an optimum growth media moisture content of 19 ±1 per cent the success ratio was found to be more than 90 per cent. Ryu *et al.* (2001) tested the improved end-effect or with cucumber seedlings at different levels of soil moisture content. Inferred that, the success rate at the medium level of soil moisture content was significantly higher than other levels.

Table 3. Analysis of variance for success rate of automatic transplanting mechanism with chilli seedlings

Source	df	SS	MS	F	PROB
Treatment	26	4252.36	163.55	117.63	0.010 **
Err	54	75.07	1.39	1.00	
Age of seedlings	2	1873.65	936.82	673.83	0.000 **
Age of seedlings (A)	2	575.44	287.72	206.95	0.000 **
Media moisture content (M)	2	939.09	469.54	337.73	0.000 **
Penetration angle (P)	4	177.56	44.39	31.92	0.000 **
MP	4	76.19	19.04	13.70	0.000 **
AP	4	404.63	101.15	72.76	0.000 **
AMP	8	205.77	25.72	18.50	0.031 **

C.V. (Treatment): 1.98%

Effect of penetration angle on success ratio

In view of the mechanical factors, the success ratio in picking up seedlings was highly influenced by the prong's penetration angle. It is indicated that the adjustment of the penetration angle was of great importance for the pincette-type gripper to pick up seedlings. The penetration angle was adjusted slightly larger to enhance its penetrating ability into the growth media. Additionally, it could also depend on the tray type and plant species under consideration. In adjusting the prongs penetration angle which pick-up plug type seedlings from the 98-cell protray, 8° was found to achieve more success ratio than other levels. There is, therefore, a great possibility for pick-up pins to grasp maximum amount of the root lump (Yang *et al.*, 1991).

Table 4. Analysis of variance for success rate of automatic transplanting mechanism with brinjal seedlings

Source	df	SS	MS	F	PROB
Treatment	26	2972.24	114.31	52.47	0.010 **
Err	54	117.63	2.17	1.00	
Age of seedlings	2	1458.92	729.46	334.84	0.000 **
Age of seedlings (A)	2	634.59	317.29	145.64	0.000 **
Media moisture content (M)	2	467.06	233.53	107.19	0.000 **
Penetration angle (P)	4	162.94	40.73	18.69	0.000 **
MP	4	53.23	13.30	6.10	0.000 **
AP	4	119.49	29.87	13.71	0.000 **
AMP	8	75.98	9.49	4.35	0.023 **

C.V. (Treatment): 2.40%

Performance test

The experimental setup (Fig. 4) was developed and tests were conducted on protray grown tomato, chilli and brinjal seedlings with 98-cells tray. At the time of study, compressor developed the pneumatic pressure of 6 kg cm^{-2}. The sequence of operations viz., penetration, grasping, extraction transferring and releasing are shown in Fig 5.

From the result it was found that, for 25 days aged tomato seedlings, the maximum success rate of 90.69 % was recorded at 19 ±1 per cent and 8° moisture content and penetration angle respectively. About 3.07 per cent of missing, 2.44 per cent of damage to the media and or seedlings and 1.39 per cent of drooping failure was recorded.Similarly for chilli and brinjal, the maximum success rate of 92.47 per cent and 91.32 per cent respectively were recorded at the same level of growth media moisture content and penetration angle with 40 days aged seedlings. Also About 2.61 per cent of missing, 2.08 per cent of damage to the media and or seedlings and 2.43 per cent drooping failures was recorded and About 2.82 per cent of missing, 3.16 per cent of damage to the media and or brinjal seedlings and 2.11 per cent of drooping failures was recorded.

Fig. 4. Performance evaluation of robotic pickup and transplanting system for protray grown vegetable seedlings

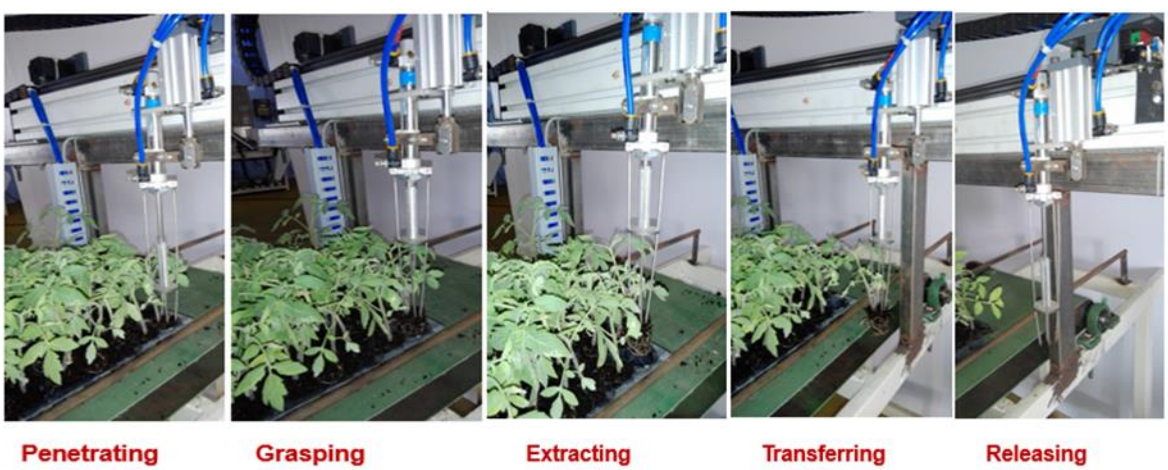

Fig. 5. Operational sequence of robotic pick-up and transplanting device

CONCLUSION

The statistical analysis of variance (ANOVA) further exhibited that the level of variables had a significant effect ($p<0.01$) on a picking efficiency in transplanting mechanism. From the experimental result it was found that, for 25 days aged tomato seedlings, the maximum success rate of 90.69 % was recorded at 19 ±1 per cent and 8° moisture content and penetration angle respectively. About 3.07 per cent of missing, 2.44 per cent of damage to the media and or seedlings and 1.39 per cent of drooping failure was recorded. Similarly for chilli and brinjal, the maximum success rate of 92.47 per cent and 91.32 per cent respectively were recorded at the same level of growth media moisture content and penetration angle with 40 days aged seedlings. Also About 2.61 per cent of missing, 2.08 per cent of damage to the media and or seedlings and 2.43

per cent drooping failures was recorded and About 2.82 per cent of missing, 3.16 per cent of damage to the media and or brinjal seedlings and 2.11 per cent of drooping failures was recorded.

Based on the experimental result it was concluded that, the optimum age of tomato seedlings, growth media moisture content and penetration angle were recorded as 25 days, 19 ±1 per cent and 8°respectively. Correspondingly, for the optimum age of chilli and brinjal seedlings,growth media moisture content and penetration angle were recorded as 40 days, 19 ±1 and 8° per cent respectively.

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REFERENCES

Bhardwaj, R.L. 2014. Effect of growing media on seed germination and seedling growth of papaya cv. Red lady. *African journal of plant science*, **8**(4), pp.178-184.

Choi, W.C., D.C. Kim, I.H. Ryu and K.U. Kim. 2002. Development of a seedling pick-up device for vegetable transplanters. *Trans. ASAE*, **45**(1): 13-19.

Garg, I.K. and A. Dixit. 2002. Design and development of tractor operated vegetable transplanter. Paper presented in 24th workshop of All India Coordinated research scheme on Farm Implements and Machinery (ICAR) held at TNAU, Coimbature, India on 18-21 April.

Han, L., H. Mao, F. Kumi and J. Hu. 2018. Development of a Multi-Task Robotic Transplanting Workcell for Greenhouse Seedlings. *Applied Engineering in Agriculture*, **34**(2): 335-342.

Kavitha, R. and V.M. Duriasamy. 2007. Development and evaluation of semi-automatic vegetable transplanter for plug seedlings. In Proceedings of the International Agricultural Engineering Conference, Bangkok, Thailand, 3-6 December. Asian Association for Agricultural Engineering.

Kumar, G. V. Prasanna, and H. Raheman. 2008. Vegetable transplanters for use in developing contries-a review. *International journal of vegetable science*, **14**(3), 232-255.

Mao, H., L. Han, J. Hu and F. Kumi. 2014. Development of a pincette-type pick-up device for automatic transplanting of greenhouse seedlings. *Applied engineering in agriculture,* **30**(4), 547-556.

Ministry of Agriculture &Farmers Welfare, Govt. of India (https://www.indiastat.com/table/agriculturedata/horticulture/118/1116167/data.aspx)

Parish, R.L. 2005. Current developments in seeders and planters for vegetable crops. *Hort. Technology*, **15**(2), 541-546.

Ryu, K.H., G. Kim and J.S. Han. 2001. Development of a robotic transplanter for bedding plants. *Journal of Agricultural Engineering Research.* **78**(2): 141- 146.

Sivakumar, S. and C.D. Durairaj. 2014. Development of a gravity fed automatic vegetable transplanter. *International Journal of Agricultural Engineering,* **7**(1), pp.177-179.

Tian, S. and L. Qiu. 2011. Design on plug seedling automatic transplanter in greenhouse. *Adv. Materials Res.* 586-589.

Xin, J., Z. Kaixuan, J. Jiangtao, D. Xinwu, M. Hao and Q. Zhaomei. 2018. Design and implementation of Intelligent transplanting system based on photoelectric sensor and PLC. *Future Generation Computer Systems*, **88:** 127-139.

Yang, Y., K.C. Ting and Gene A. Giacomelli. 1991. Factors affecting performance of sliding-needles gripper during robotic transplanting of seedlings." Applied Engineering in Agriculture **7**(4): 493-498.

Zhou, T., X. Wang, C. Wang, L. Zheng, X. Li, X. Qiao, and C. Wang. 2009. Design and simulation analysis of transplanter for potted tray seedlings in greenhouse. *Machine Design Res.,* **25**(2): 121-124.

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