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Research Article

Factors influencing the performance of mechanical end effector during automatic transplanting of tomato seedlings

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Abstract
A number of elements of probabilistic nature mightily influence the picking efficiency of a transplanting mechanism. There are two key factors to be considered in the development of seedling pickup devices. One is the mechanical features of the end effector, and the other is the horticultural features of the protray seedling. The investigation aimed to find the features affecting the transplanting of protray grown tomato seedlings using mechanical end-effectors. Various mechanical linkage-picking fingers were developed and tested with an experimental setup for gripping and releasing the seedling. Two different pneumatic cylinders triggered the mechanical end effector, one for holding the seedling and then ejecting the seedling from the protray. When all the seedlings were ejected from the initial line of the protray, the endless belt shifted the protray just below the end-effector mechanism. Assessments were carried out with moisture content of media (16 ±1, 18 ±1 and 21 ±1%), mechanical end-effector (sliding plate cam type, sliding end cam type and four bar type picking finger) angle of end-effector needle (6, 8 and 10 deg.) to enhance the picking, transmission and dropping with low missing as well as harms for the seedlings. The minimum value of missing seedlings (6.55 %) and maximum success rate of picking (93.45 %) were noted at 18 ±1% of the growth media moisture content (M_2) and at 8 deg. angle of gripper needle (θ_2) with a sliding plate cam-type picking finger (F_1). The transplanting frequency was 840 seedlings h^{-1}.

Keywords: Mechanical end effector, Moisture content protray, Seedlings, Transplanting frequency

INTRODUCTION

The present system of vegetable cultivation is to transplant the seedling by hand with the help of female workers (Nandede and Raheman, 2016). The work is a tedious and labour-requiring operation. Transplantation in the bending position requires an extra energy expenditure of 8 kJ min-1 and increases the heart rate by 51% (Khadatkar *et al.,* 2018).

When developing automatic transplanters, nursery seedling ejection and plant setting are important features to consider. The automatic transplanter needs either plug or pot seedlings. Ejection of the single seedling from the protrays at rates of 3 to 5 seedlings s^{-1} is essential. The primary investment in the production of seedling plugs is increasing, and the mechanisms working to eject the seedlings from the tray are difficult. The important complication for investigators in developing a fully automatic transplanter is the technology of ejecting the seedling from the tray (Gao, 2016).

A number of elements of probabilistic nature mightily influence the picking efficiency of a transplanting mechanism. There are two key factors to consider in developing seedling pickup devices. One is the mechanical features of the end effector, and the other factor is the horticultural features of the protray seedling. The goal of the investigation was to find the features influencing the transplanting of seedlings with mechanical end-

effectors. Various mechanical end-effectors were developed and evaluated to hold and release the seedlings with an experimental setup.

MATERIALS AND METHODS

Two key components were considered in the fabrication of an automatic transplanting mechanism for plug seedlings. Since the removal mechanism is a challenging operation in effector, the other step is ejecting the seedling from the protray cell. Three kinds of mechanical end-effector (Fig. 1) were fabricated and evaluated with an experimental setup to hold, eject, transfer and release the tomato seedlings. Assessments were carried out with the moisture content of the media, mechanical end-effectors and angle of the end-effector needle. The result was recorded in terms of proper ejection, transmission and delivery with minimum missing data and harm to the seedlings.

Effect of media moisture content on missing and picking of seedlings

The favourable range of media moisture content is essential, which would ease the removal of seedlings from protray cells without any missing information or damage. Hence, the media moisture condition was inspected in this experiment. The levels of media moisture content on a wet basis were fixed as 16 ±1, 18 ±1 and 21 ±1% (Mao *et al.,* 2014).

Effect of mechanical end-effector on missing and picking of seedlings

Three kinds of mechanical end-effectors were developed and tested with protray grown vegetable tomato seedlings for gripping, removing and dropping.

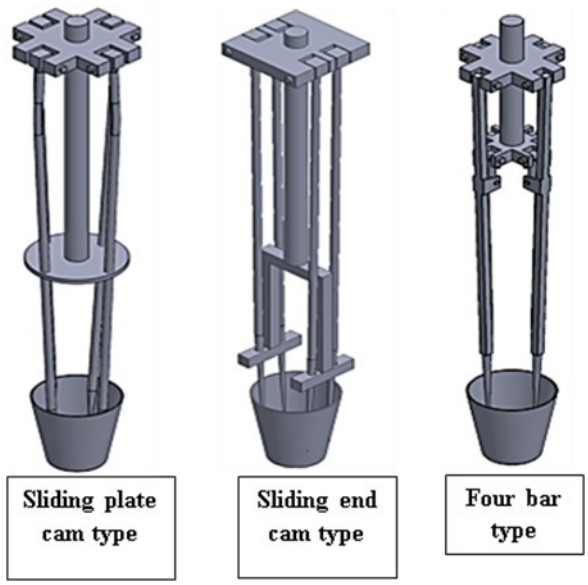

Fig. 1. *Mechanical end effectors for picking and dropping of protray seedlings*

Effect of the gripper needle angle on missing and picking of seedlings

In seedling grasping, the end effector is associated with the electromechanical device and the biological material. In addition, the angle of the gripper needle (θ) must be less than the taper of the tray cell (Liu *et al.,* 2015 and Liu *et al.,* 2016). It is ensured that the needles hold the largest amount of root mass. Therefore, the locality of the needle with respect to the tray cell is very important. This can be found in the angles of the needles during the grasping action. Hence, the study was conducted in tomato plug seedlings with different angles (6 deg., 8 deg. and 10 deg.) gripper needles and the percentage of successful picking and dropping were assessed (Mao *et al.,* 2014).

Development of a transplanting mechanism for portray grown seedlings

An experimental setup was developed, as shown in Fig. 2. It consisted of a mainframe, linear extrusion, guideway, linear rail, stepper drive, stepper motor with pulleys, SMPS, PLC board, solenoid values with coils, relay board and conveyor.

A separate cylinder was used to grip and eject the seedlings. The picking cylinder implements the picking action and the removal of the seedling from the protray cavity. This cylinder is mounted on a linear guide, and a 5A stepper motor drives the carriage. A PLC with a

Fig. 2. *Automatic picking and transplanting mechanisms for protray grown vegetable seedlings*

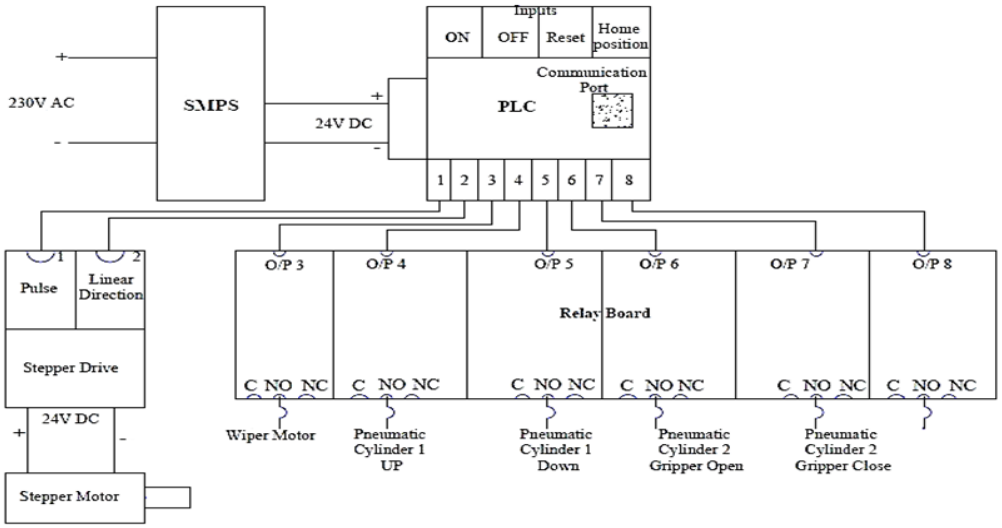

Fig. 3. *Control unit of the entire transplanting system*

microcontroller was used to control the stepper motor to position the picking cylinder just above the protray cavity. The mechanical linkage picking fingers are actuated by pneumatic cylinder pressure at 6 kg cm^{-2}. The control unit of the entire transplanting system is shown in Fig. 3. The operational sequence is given in Fig. 4 in the form of a flow chart.

Two pneumatic cylinders were used, one to hold the seedling and the other to eject the seedling from the tray cell. A belt conveyor was utilized for automatic movement of the protray at regular intervals, and the drive was taken from a 45 rpm DC motor. The entire system was controlled by PLC programming. A solid-state relay was utilized to actuate the DC motor. When all the seedlings were ejected from the initial line of the protray, the endless belt shifted the protray just below the end-effector mechanism. The displacement of the tray with respect to time was measured and integrated with the programme. The transplanting frequency was 840 seedlings h^{-1}.

Optimization of selected levels of variables for mechanical linkage picking finger

A study was conducted on the selected variables to optimize the automatic transplanting mechanism with tomato seedlings. The measured parameter was recorded for all the treatments of investigation. Tomato seedlings were grown in 98 cell plates with coir pith growth media, and 25-day-old seedlings were used for the study. The experimental results were utilized to evaluate the adaptability of the end effector. The affecting parameters were analysed with AGRES software. The optimized level of variables was adopted for the automatic transplanting mechanism. The optimum range of the variables was investigated based on the maximum successful ejection, transmission and dropping with low missing and harm to the seedlings.

RESULTS AND DISCUSSION

Effect of variables on missing seedlings in tomato seedlings

The minimum value of missing seedlings (6.55%) was recorded in 18 ±1% (M_2) of media moisture content at 8 deg. (θ_2) angle of gripper needle with end effector-I (F_1), whereas the maximum of 24.65% was recorded in 21 ±1% (M_3) of media moisture content at 10 deg. (θ_3)

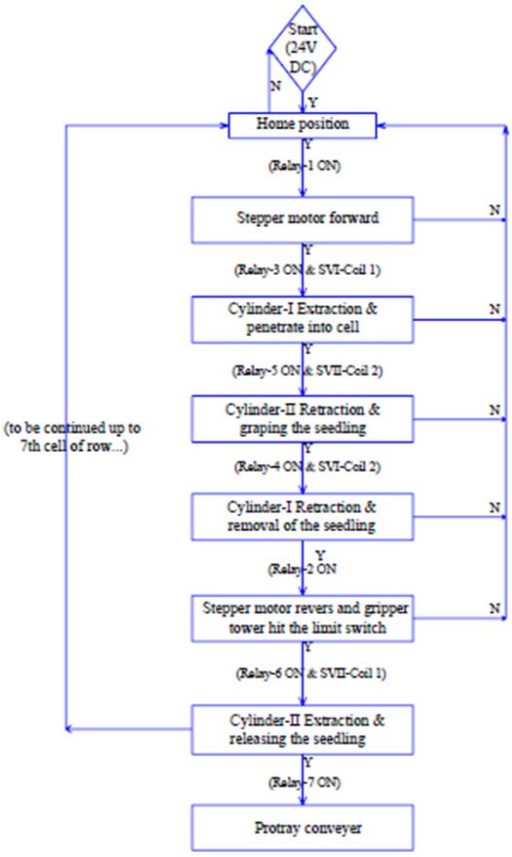

Fig. 4. *Block diagram of the operational sequence of the transplanting mechanism*

angle of gripper needle with end-effector-III (F_3) for tomato seedlings (Fig. 5).

ANOVA of selected variables on missing tomato seedlings

The results of ANOVA indicated that there was significant among the treatments. The influence of variables was at the one % level of probability. The interaction effects of M x F, F x θ, M x θ and M x F x θ were significant at the 1% level probability. This resulted in the interaction *viz.,* M_2 x F_1 x θ_2 being found to be the best treatment, and the interaction of M_3 x F_3 x θ_3 being found to be the poorest treatment.

Effect of variables on the success rate in tomato seedlings

The minimum success rate (75.35%) was registered at a medium moisture content of 21 ±1% (M3) at 10 deg. (θ_3) angle of gripper needle with end-effector-III (F_3), whereas the maximum of 24.65% was recorded in 18 ±1% (M_2) of media moisture content at 8 deg. (θ_2) angle of gripper needle with end-effector-I (F_1) in tomato seedlings (Fig 6). This is because when the end-effector needle was at an angle of 8 deg., the needles grasped the largest amount of media mass, whereas the end-effector could not hold the adequate amount of media at 6 deg. angle of the end-effector needle (θ_1) and unsatisfactory results in the removal of seedlings.

ANOVA for selected variables on success rate in vegetable seedlings

The individual and interaction between all treatments of variables were significant at the 1% probability level. The interaction of M_2 x F_1 x θ_2 was the best treatment, while the interaction of M_3 x F_3 x θ_3 was found to be the poorest treatment. The above results were though in lined with the findings of Khadatkar, *et al.,* (2018) on vegetable seedlings, the treatment combinations were significant at 5% level only.

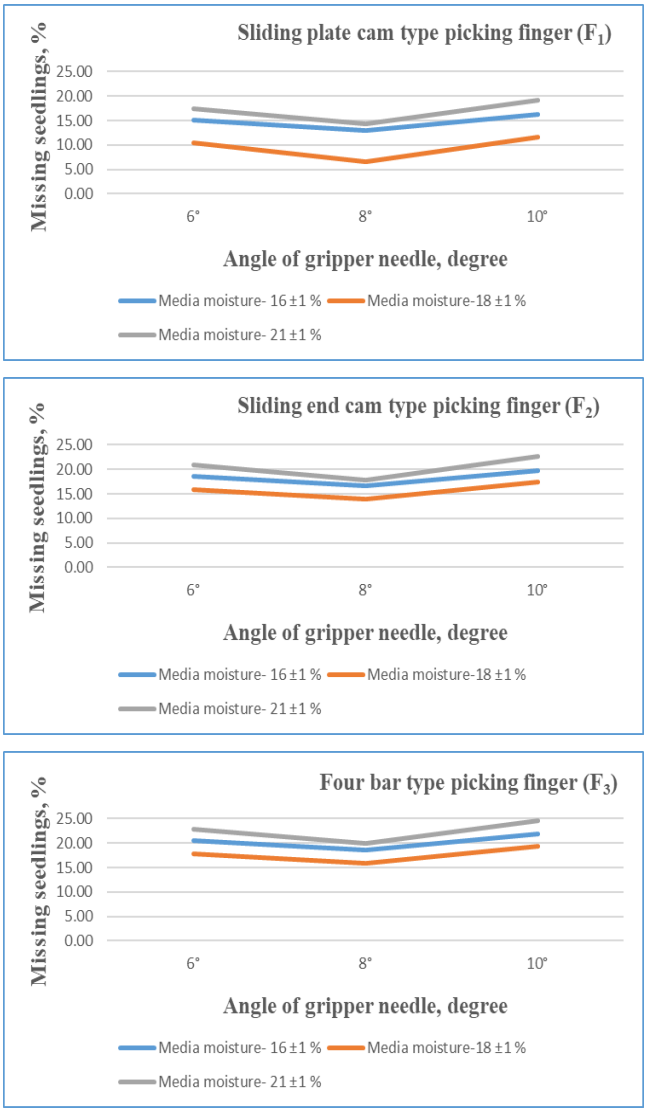

Fig. 5. *Effect of variables on missing tomato seedlings*

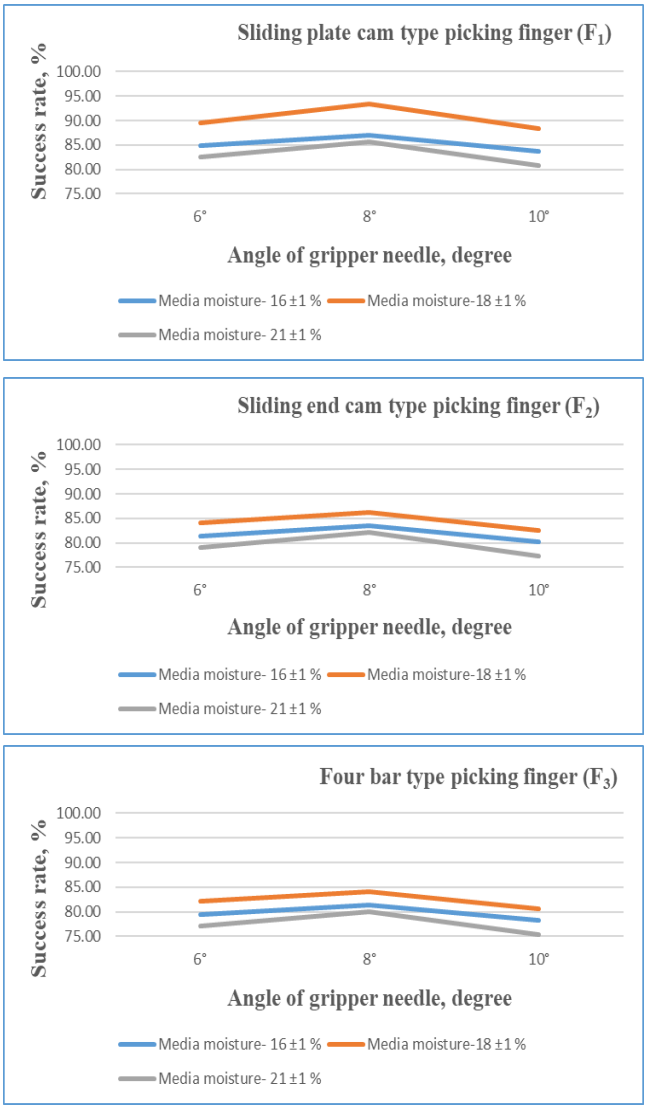

Fig. 6. *Effect of selected variables on success rate in tomato seedlings*

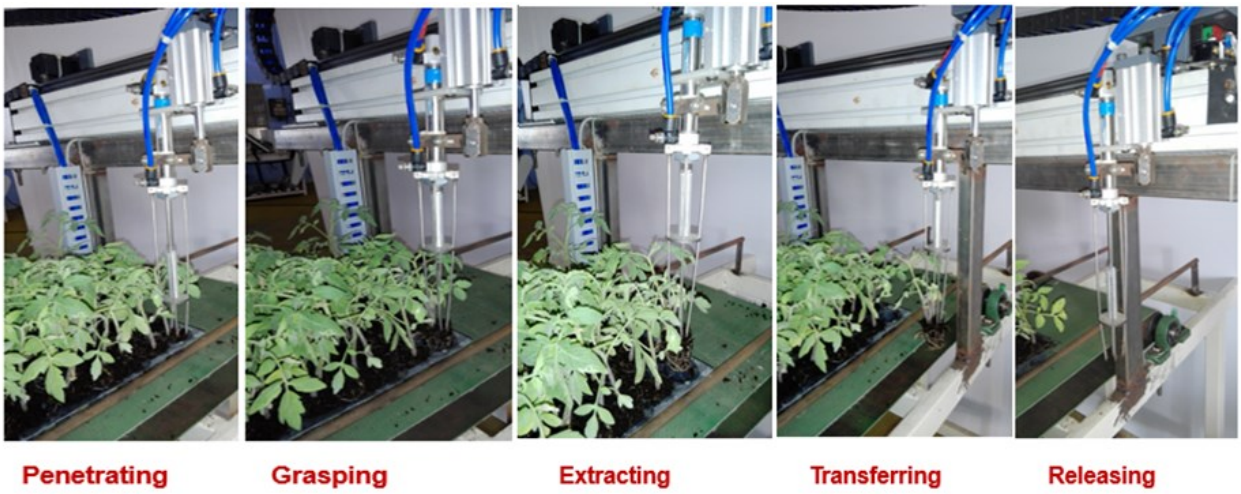

Fig. 7. *Operational sequence of automatic picking and transplanting mechanism*

Optimization of machine operation with selected parameters for mechanical linkage picking fingers

The combination levels of 18±1% media moisture content (M_2), end-effector-I (F_1) and 8 deg. The angle of the gripper needle (θ_2) was the optimized variable for 25-day-old tomato protray grown seedlings. The sequence of operations, *viz.,* penetration, grasping, extraction transferring and releasing, is given in Fig. 7. The maximum picking and transferring success rate were recorded as 93.45 % for tomato seedlings, but in the other techniques, such as sliding end cam and four bar type end-effector, it was minimum (77.35 and 75.35 %, respectively).

Conclusion

The mechanical linkage picking fingers for protray grown tomato seedlings were developed and evaluated in an experimental system to hold, eject, transfer and deliver the tray seedlings. Evaluation carried out with three levels of media moisture content, mechanical end -effectors and angle of end-effector needle for assessing maximum success, ejection, transmission and dropping with minimum missing and damages to protray grown selected vegetable seedlings showed that the minimum value of missing seedlings (6.55%) and the maximum success rate of picking (93.45 %) were recorded at 18 ±1% growth media moisture content (M_2) and at 8 deg. angle of gripper needle (θ_2) with end -effector-I (F_1).

This device was capable of developing a working model of an automatic vegetable seedling transplanting mechanism, which can grasp the seedling from a protray and transfer them. The transplanting frequency was 840 seedlings h-1. The statistical analysis of variance (ANOVA) further showed that the level of variables had a significant effect ($p<0.01$) on the picking efficiency in the transplanting mechanism.

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Conflict of interest

The authors declare that they have no conflict of interest.

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