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Advancement in Vegetable Transplanting: Mechanization, Challenges and Opportunities

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Abstract:- The transplanting operation is required higher labour intensity and lower efficiency for the operation by hand in vegetable production. It is largely done by hand in India and vegetable transplanting is a time-consuming field operation when performed manually. This makes it necessary to adapt the mechanization for vegetable transplantation to save money and time and increase the productivity to fulfil the food requirement of a huge population. Due to the growing demand for vegetables all year round, the use of vegetable transplanters has become widespread in agricultural production. Hand transplanting of vegetable seedlings is always been a time consuming and laborious activity which often leads to muscular fatigue. The work is drudgeries and laborious as the operation is done in a bending and squatting posture. The semi-automatic vegetable transplanters are heavy to operate due to limitations on manual feeding rates of seedlings which vary with respect to work duration and skill of the operator. Automation in the field of vegetable transplanters has provided opportunities for savings in labour and time required for transplanting operation. The beginning and current advances in transplanting technologies suggest ample scope of working on automated seedling pickup and drop mechanisms using robotics. This study highlights the discuss vegetable transplanter and advances in transplanting technologies used in the field.

Keywords:- *Vegetable, Automation, Transplanter, Seedling, Transplanting Technology.*

I. INTRODUCTION

India has the second-highest production and consumption of vegetables after China. Then cultivation and production are increasing day by day, because vegetables are one of the most important food items in the Indian diet, without which any is incomplete. According to the Ministry of Agriculture and Farmers Welfare, Government of India 2021-2022 estimate, a record 342.33 million metric tonnes are estimated to be produced in an area of 28.08 million hectares. The total horticulture production is estimated to be 342.33 million metric tonnes in the years 2021–22, showing an increase of about 7.73 million metric tonnes (an increase of 2.3%) over the years 2020–21 (final). Production of vegetables is estimated to be 204.84 million tonnes as against 200.45 million tonnes in 2020-21. (Ministry of Agriculture and Farmers Welfare, GoI 2021-2022). About 175 types of vegetables are grown in India, including 82 field vegetables and 41 root (tuber and bulb) crop (Subramanian et al.,2000) However, the yields of most species are far below their world averages; improving productivity or production efficiency is required to meet the growing national demand as well as to remain economically competitive in the global market.

Mechanised cultivation, along with other improved crop production practices, can increase crop yield and quality. However, the planting and harvesting processes were mainly manual, which made the operation inefficient and of lower quality. At the same time, it reduced the economic benefits of vegetable production and restricted the development of the vegetable industry.

Generally, seedlings of vegetables like tomatoes, brinjal, chilli, cabbage, garlic, etc. are raised in nurseries. There are several activities that include preparing the field for placing the seedling, transporting the seedling from the nursery to the field, and planting at the desired spacing and depth in the vegetable transplanting operation. The traditional practice is to hold a bunch of seedlings in one hand, separate seedlings with the other hand, and press down the roots in the soil with bare hands. The work is drudgery and laborious as the operation is done in a bending and squatting posture. The labour requirement in manual transplanting of vegetable seedlings varies from 180 to 420 man-hours per day. However, labour shortages during peak season cause delays in transplanting, leading to the mortality of seedlings and eventually yield loss.

II. CLASSIFICATION OF THE VEGETABLE TRANSPLANTER

- *Traditional Methods of Transplanting Vegetable Seedling*

A well-pulverized seed bed is prepared in medium and large fields in India, and raised beds 90–120 cm wide and 30 cm high are built manually or with tractor-drawn implements. Bare root seedlings are removed from nursery

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beds and manually transplanted in rows at recommended spacings in raised beds. A spade is used to compact the soil around the seedling. This is known as raised-bed planting. Transplanting eggplant, onions, and chilli peppers takes 185–260 man-hours per year. (Punjab Agricultural University [PAU], 2004). Furrows are sometimes opened with tractor-drawn implements, and seedlings are planted by hand in furrows. (Marr, 1994). Raised beds are not prepared on some farms due to a lack of mechanisation. Following the preparation of the seed bed, seedlings are manually transplanted in rows, covered with soil, and compacted. As the plants grow, ridges and furrows form. This is known as flat-planting. This method requires approximately 320 man-hours ha-1 for tomato transplanting at 60 cm row-to-row spacing and 45 cm plant-to-plant spacing. (Central Institute of Agricultural Engineering [CIAE], 2004). A few low-cost hand-held vegetable transplanters with field capacities of about 0.02 ha h-1 and field efficiency of 82.3% have been developed. (Patil A.S. et al.)

➢ *Vegetable Transplanters Execute Several Tasks in the Field, as Outlined by Srivastava et al. (2006):*

- Creating furrows to a specified depth
- Regulating the spacing of seedlings in rows
- Inserting seedlings vertically into furrows or holes
- Ensuring adequate soil coverage over the seedlings
- Compacting the soil around the seedlings to secure them.

➢ *Mechanical Transplanting Involves Three Essential Functions:*

- Opening the soil to form narrow furrows
- Placing seedlings vertically in the furrows
- Closing and compacting the soil around the seedlings without causing damage.

The vegetable transplanter can be categorized as either automatic or semi-automatic. Current systems mostly fall into the semi-automatic category, employing pocket-type, cup-type, bucket-type, or conveyor-type metering mechanisms. These mechanisms accommodate bare root, plug, or paper pot-type seedlings for transplantation. However, it's noted that these existing systems tend to be expensive, require significant labor input, and demonstrate lower field efficiency.

➢ *Semi-Automatic Vegetable Transplanter:*

The Walk-behind transplanters can be attached as an extension to self-propelled prime movers or power tillers. Due to the necessity for manual insertion of seedlings into the cups by the operator, these transplanters are prone to missing seedling placement, especially at higher transplanting rates. Riding-type transplanters, on the other hand, are usually mounted on tractors and are available in configurations of two to three rows. Furthermore, there have been advancements in semi-automatic vegetable transplanters designed for seedlings cultivated from plugs, bare roots, or paper pot.

➢ *Automatic Vegetable Transplanter:*

An automatic vegetable transplanter can be a riding or walk-behind machine, reducing the labour intensity of seedling (Parish R.L., 2005). When there are more than four rows, riding-type transplanters are either self-propelled or tractor-operated, whereas walk-behind transplanters are generally self-propelled. Automatic vegetable transplanters are not available in India due to a lack of available equipment at an affordable price for farmers.

➢ *Automation in Vegetable Transplanting*

To ease of the transplanting operation, different types of metering mechanisms have been developed for mechanical transplanters. These include linked-chain-type, pocket-type or finger type, cup- or bucket-type, rotary cup-type, conveyor-type, and seedling pick-up type mechanisms.

III. LINKED CHAIN-TYPE MECHANISM

The linked chain-type mechanism is generally used for transplanting potted seedlings in semi-automatic vegetable transplanter and automatic vegetable transplanter, viz. tomato, cabbage, garlic, broccoli, etc. These seedlings are cultivated in hexagonal paper trays or connected by a continuous chain, and the system is either pulled by manually or by power source.

Patil N. (2018) developed the single row automatic garlic transplanter. These prototypes suitable for paper chain pot seedling. The plant to plant spacing maintained precisely 10 cm. The machine can achieve 28.4 mm depth of transplantation. The average damaged seedlings in this machine are very much low that is 0.520. The average furrow closer can be best achieved as 97.5% and the 89.81º standing angle of seedlings can be achieved which is very much closer to 90º. The field capacity of transplanter was 0.0432 ha/hr with field efficiency 75.19 percent. The draft of machine was 145 kg.f. the labour requirement in this machine was 32 man-hr/ha. The average cost for transplanting 1000 seedlings using this transplanter was Rs. 45.36. The Saving in cost of transplantation over manual transplantation was 55.84 percent.

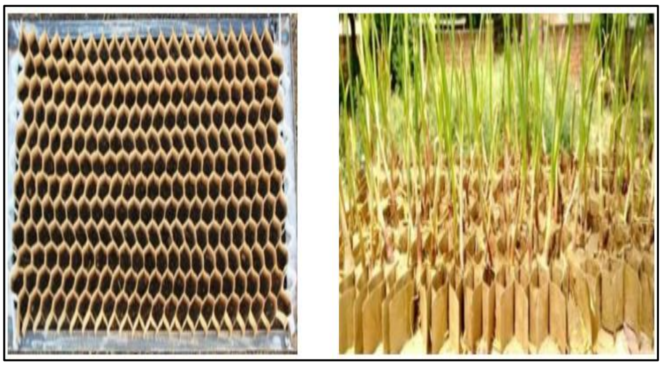

Fig 1 Paper Chain Pot Type Mechanism

Suggs et al. reported the working principle of two proprietary machines for transplanting strand of paper-pot seedlings. The seedlings are held between pair of hands by the machine's Ferris wheel transplanter, which revolves into

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the furrow before releasing the seeds. At a planting rate of 100 seedlings per minute, it can be effectively used. The other device, a roll feed transplanter, feeds the seedlings in a strand between a pair of feed rollers and into a pair of accelerator rollers, which rapidly rotate in order to break the strand and force the seedlings into the drop tube. This transplanter can plant 140 seedlings min^{-1}.

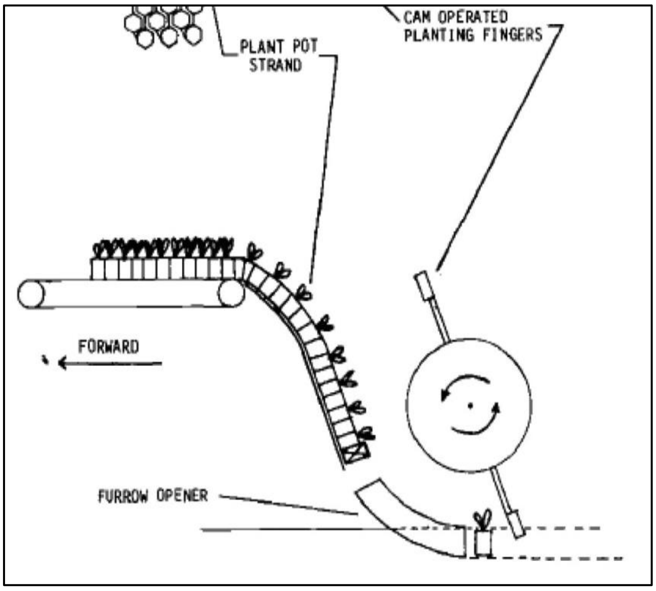

Fig 2 Linked Chain-Type Mechanism (Suggs C. 1987)

Tsuga K. developed three models of two-row riding-type automatic vegetable transplanter These prototypes were effective for growing lettuce, Chinese cabbage, and cabbage seedlings in cell mould and pulp mould cell pots. The annual use and break-even area transplanted in Japan was reported to be 53 and 8.2 ha $year^{-1}$, respectively.

Kumawat L. developed a 15 hp mini tractor operated 4-row automatic onion transplanter to transplant onion seedlings raised in hexagonal shaped (honeycomb) paper pot chains with lengths of 800 mm, widths of 180 mm, and depths of 40 mm. This paper pot chain raises a total of 128 seedlings. The onion transplanter was designed to transplant four rows of onion seedlings at a time, with a 10 cm spacing between each row. It included a furrow opener, a covering device, a conveying belt and cutting units, a seedling delivery tube for each of the four rows, and two ridges for making two 40 cm wide ridges at the top. The developed transplanter's average effective field capacity for transplanting onion seedlings is 0.071 ha/h with a field efficiency of 71.25%, and the average missing index and multiple index are 33% and 18.77%, respectively.

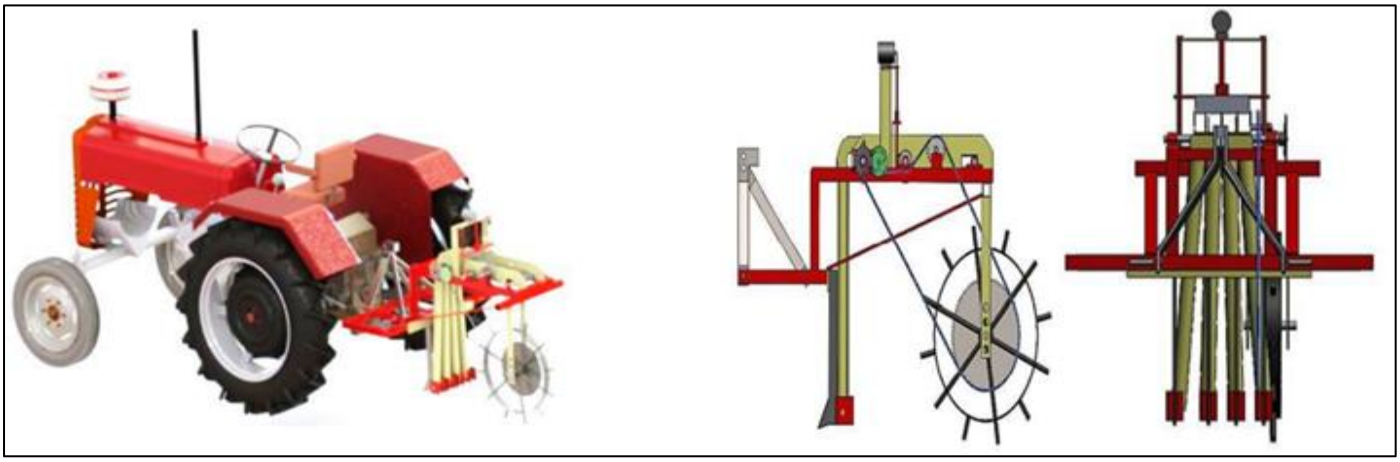

Fig 3 Schematic Views of the Onion Trans planter (Kumawat L. 2020)

Fig 4 Side View of the Developed Onion Trans planter (Kumawat L. 2020)

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- *Pocket-or Finger Type Mechanism*

A pocket-type metering mechanism is usually used for transplanting bare root seedlings in semi-automatic vegetable transplanter, viz. eggplant, tomato, cabbage, cauliflower, sweet potato, broccoli. The device comprises of 6–12 spring-loaded pockets spaced evenly along a drum.

Singh S. reported two-row tractor mounted vegetable transplanter developed and evaluated at Punjab Agriculture University, Ludhiana for bare root seedlingsA pocket (picker wheel)-type metering mechanism, operated by the ground wheel of the transplanter, was utilized. By adjusting either the sprockets or the number of plant pockets on the metering system, the spacing between plants in a row could be varied from 30 to 60 cm. The percentage of missed plantings ranged from 2.0 to 3.5, depending on the plant spacing in the row and the skill of the operator, with a forward speed of 0.8 to 1.0 km/h. This machine also offered an optional bed-forming attachment, allowing both bed formation and transplanting to be completed in a single pass, thereby saving time, labor, and energy. Chaudhari et al. developed a two-row semi-automatic tractor-drawn finger-type vegetable transplanter specifically for transplanting bare root vegetable crops such as tomato, brinjal, cauliflower, chili, etc. Kazmeinkhah K. designed a stickling-type semi-automatic vegetable transplanter for sugar beet. It was found that sticklings could be planted at a target depth of 13 cm, with rows spaced 65 cm apart and plants spaced 50.3 cm from each other. Stickling placements deviated by 4.5% along the row and by 3.6% perpendicular to the row from their intended positions. When operating at a forward speed of 0.6 km/h and planting at a maximum depth of 18 cm, a draft force of 4.05 kN was required.

- *Rotary Cup-Type Mechanism*

The rotary cup-type metering mechanism is usually used for transplanting potted seedlings in semi-automatic vegetable transplanter, viz. tomato, cabbage, cauliflower, celery, lettuce, chilli, etc. A horizontal rotating shaft, circularly attached cups, a delivery tube, and a soil compaction wheel make up the device. Manual feeding of the seedlings into the delivery tube is required.

Choon Y. K. reported that, the walk-behind type, single-row, semi-automatic vegetable transplanter made in Japan and driven by a 2.25 kW gasoline motor is suitable for ridge planting chilli seedling plugs on plastic mulches. A rotating cup-type measurement equipment with 6–8 circularly attached cups on a shaft rotating in a horizontal plane was provided to the transplanter. The cups were filled with seedlings as the shaft turned, and the seedlings were carried to the bottom of the cup, where the cup opened and dropped the seedlings into the furrow. The ranges for adjusting the row and plant spacing in a row are 0.8-1.0 m and 0.35-0.6 m, respectively.

Craciun V. and Balan O. developed tractor-mounted semi-automatic vegetable transplanter for transplanting of pot seedlings of tomato, chilli, cabbage, broccoli, onion and watermelon. With a minimum row spacing of 30 cm, a rate of 60–80 seedlings per minute per row were transplanted. For onions, the minimum plant spacing was 9.5 cm, and the maximum plant spacing was 63.3 cm.

Narang et al. developed two-row vegetable transplanter with a rotating magazine-type metering mechanism and tested on a brinjal crop in the field. The brinjal seedlings were raised in soil-free media in 98-cell plug trays with single cells that had a volume of 22 cm3. Miss planting percentage ranged from 2.22 to 4.44. Plant mortality 20 days after transplanting was reported to be 3.33–4.0% for plants that were transplanted upright with a planting angle of 300 and a depth of planting between 50 and 60 mm.

- *Cup- or Bucket-Type Mechanism*

The cup- or bucket-type metering mechanism is usually used for transplanting potted seedlings in semi-automatic vegetable transplanter and automatic vegetable transplanter, viz. eggplant, tomato, chilli, etc. The device consists of a soil compaction wheel, delivery tube, and conical cup. The soil-compacting wheel-driven drum is fitted with the conical cups.

Imad H. developed and tested a 45-kW tractor-mounted single row transplanter that uses a feeding belt technology to speed up the establishment of block or bare-rooted transplants.

Munilla R. D. and Shaw L. developed a high-speed dibbling transplanter that takes seedlings straight out of a growing tray. The operations of digging the holes, taking the plants out, and putting them back in were all completed at zero relative speed.

Brewer H.L. developed a prototype single-row automatic vegetable transplanter that delivered bare-plug seedlings into revolving discs through static cassettes. According to studies, 60–300 seedlings per minute are transplanted at 300 mm plant–to–plant spacing. For transplanting, short, strong seedlings are required.

- *Conveyor-Type Mechanism*

The conveyor-type metering mechanism is commonly used for transplanting potted seedlings in semi-automatic and automatic vegetable transplanters, such as tomato, cabbage, celery, broccoli. etc. A horizontal belt conveyor and a soil compaction wheel make up the unit. The belt can be plain or have a series of cross-wire partitions where seedlings can be placed. A chain drive drives the belt conveyor from the machine's ground wheel. The plug seedlings are manually placed in batches on a horizontal (feeding) conveyor with cross-wire partitions and delivered to split cone cups.

Feng et al. described the development of 8.8 kW four-wheel drive tractor-powered fully automatic 2ZG22 transplanter available in China. The seedling tray contains 100 seedlings, ten in each row. During the operation, a single row of ten plug seedlings from the tray is aligned with the belt conveyor, and the seedlings are pushed to the belt conveyor by the operator. The seedlings are transported by belt conveyor to the metering device, which blocks and then

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releases the plug seedlings according to the timing set using a cam-operated controller to achieve the required plant spacing in the row.

Kumar and Raheman developed a 9.75 kW walk behind-type hand tractor powered two-row fully automatic vegetable transplanter for individual paper-pot seedlings. Two upright feeding conveyors on the vegetable transplanter carry 108 seedlings, which are then delivered to the metering conveyors to be planted upright in furrows.

➢ *Seedling Pick-up Type Mechanism*

The seedling pick-up type mechanism is developing because it allows for accurate, precise, and effective seedling planting with the least amount of human involvement. A key idea in this situation is seedling pick-up, in which a single seedling is automatically extracted from the tray using a pair of pins or forks, released into the furrow, and then returned back to its starting place. This kind of mechanism extracts the seedling using an end-effector mechanism and computer graphics or machine vision technology.

Luhua Han et al. developed the riding type fully automatic transplanter is developed being suitable for plug seedlings. The developed transplanter has an average effective field capacity of 0.071 ha/h, a field efficiency of 71.25%, and average missing index and multiple indexes of 33% and 18.77%, respectively. Up to 90% of attempts to pick up seedlings are successful.

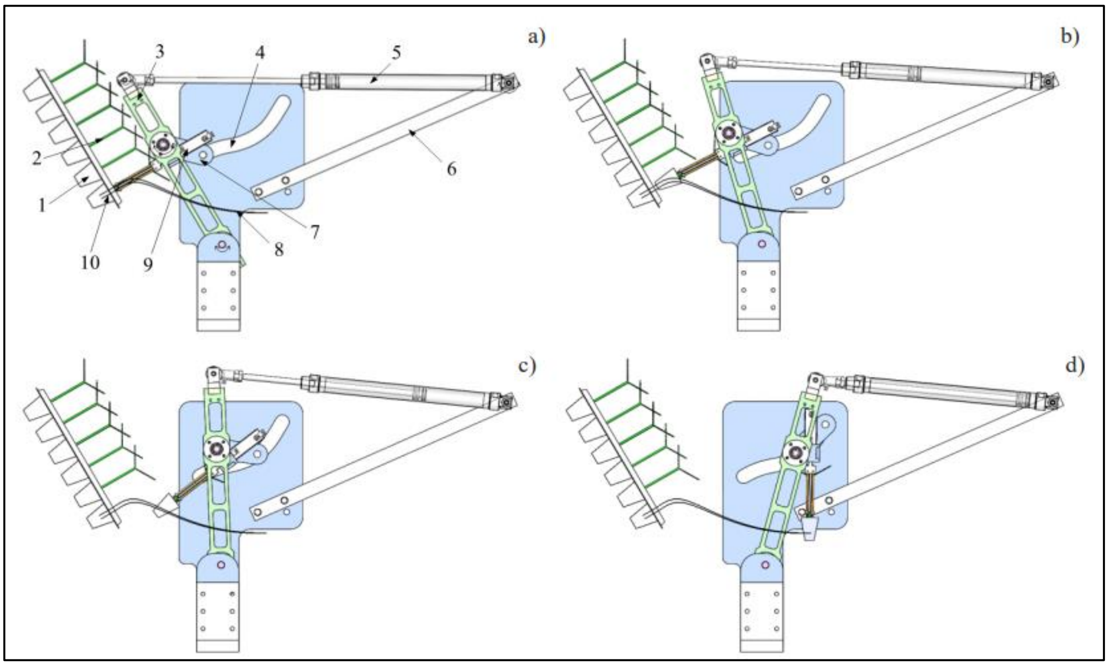

Fig 5 Conceptual Working of the Path Manipulator: 1) Plug Tray;2) Plug Seedling;3) Rocker;4) Fixed Groove;5) Driving Cylinder;6) Frame;7) Connecting Link;8) Picking up Trajectory;9) Gripper;10) Pick-up Pins.(Luhua H et al., 2019)

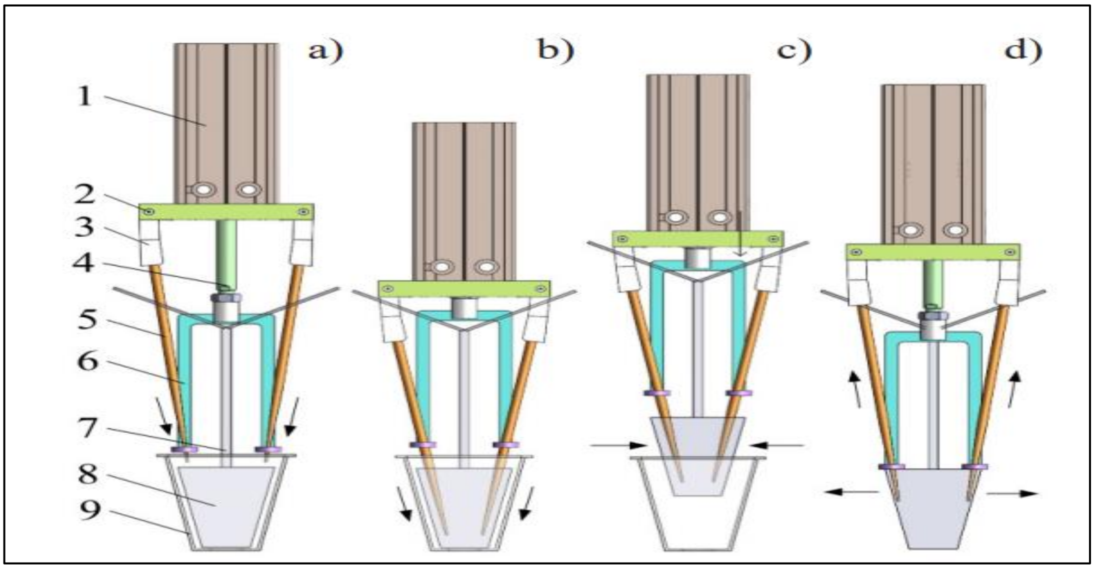

Fig 6 Operation of the Gripper for Seedlings Extraction;1) Cylinder Block;2) Shaft;3) Swinging Finger;4) Piston;5) Pick-up Pins;6) U-Type Pull Rod;7) Seedling;8) Root Soil;9) Tray Cell.(Luhua H et al., 2019)

Davood M.Z. developed fully automatic tomato transplanter with a seedling pick-up arm. It has a main chassis, a mechanism for moving seedling trays into the pick-up arm position, a mechanism for picking up seedlings from trays, a crash tube, a furrower, and a control system. A step mechanism gradually moves the tray to the left, right, and down sides so that the pick-up arm can lift a seedling by penetrating the soil's needles. The pickup arm then moves to the crash tube's position to release the seedling with the soil pot. The seedling then drops in the furrow that the furrower made. 1 km/h forward speed, the theoretical capacity of the single-row machine, 0.06 ha.h-1 is determined.

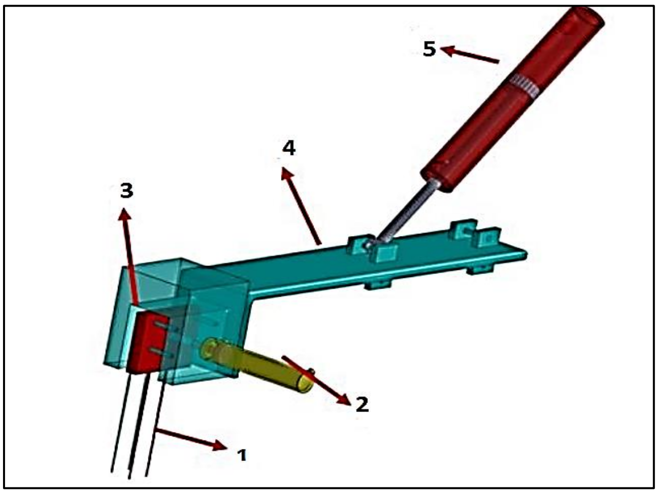

Fig 7 Pick up Arm from Tray (1-Niddles 2-Cylinder of Needles 3-Cylindr of Pick-up Arm 4- Pick up Arm 5- Shifting Plate) (Davood M.Z.)

Jin X. et al. developed a single row automatic transplanting device for potted vegetable seedlings. The design of an automatic transplanting device for vegetables includes a rotary planting mechanism, a control system, a five-bar fixed and axis gear system combined seedling extraction mechanism, and a horizontal and longitudinal tray moving mechanism. The device can properly pick up the seedling and easily transplant vegetables and also automatically transfer seedlings in pots. The success percentage of extracting seedlings ranges from 92.59% to 77.78%, and the transplanting frequency is 60–120 plants per minute.

IV. CONCLUSION

Mechanization in vegetable transplanting is improved efficiency and increased output. The demand for vegetables is increasing as the population grows and people become more health conscious. In order to meet this demand and export high-quality vegetables in a timely manner, Indian farms must be mechanized. Manual and semi-automatic vegetable transplanters are very cost effective for mechanization in Indian farms in terms of operating and servicing costs. The field capacity and accuracy of automatic transplanters are higher, but the high initial cost, complicated mechanism, and servicing facility make them uneconomical in Indian farms. According to a study of the literature the existing vegetable transplanters have low field efficiency. Due to the single-row machine's low capacity, it has been observed that more labour is needed for transplanting than is usual. Low field capacity is the result of the machine's operating speed being restricted to 1 km/h in order to prevent miss planting. This implies that there is ample scope for developing automated metering mechanisms for vegetable seed pick-up and drop using robotics in agriculture.

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