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Design And Development of Five- Bar Linkage Mechanism for Automated Vegetable Transplanter

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Abstract - This research paper represents the design and development of a Translating Five-Bar linkage mechanism for an automatic vegetable transplanter, aimed at enhancing the efficiency and precision of agricultural transplantation processes. The Traditional transplanting of seeds is Time consuming, Labour intensive and costly activity which provides uneven plant laying and low transplanting rate. This system uses a duckbill type Five-Bar linkage mechanism which is powered by the tractor's (PTO) Power Take-Off shaft. This driving mechanism consists of 2 crankshafts, connecting rods, and chain sprocket arrangement to achieve the best seedling placement, ensuring minimal soil disturbance and precise transplantation. This design includes kinematic analysis of the Five-Bar linkage to optimize the motion trajectory of the planting mechanism, focusing on uniform planting depth and linear spacing. This study includes the parts design and motion analysis, simulation and kinematic analysis through CAD modelling software. The integrated system enhances the energy efficiency of the mechanism, making it suitable for diverse field conditions and various crop varieties and the experimental results has shown that this system achieves reliable and consistent transplantation with reduced manual effort, proper plant laying and improved transplantation rate.

***Keywords*:** Five-Bar linkage, PTO, Vegetable transplanter, Sapling

1.INTRODUCTION

India has been recognized as the leading producer, consumer, and exporter of chilli, onion, and brinjal globally since 2021. Historically, vegetables in India have been cultivated on small plots of land, but organic farming has recently gained traction. Onions and chillies are staples in daily diets due to their nutrient-rich properties and contribution to a balanced diet. The demand for these vegetables is steadily rising as their consumption grows. Despite the impacts of the COVID pandemic, the export of chillies and onions from India increased during the 2019-20 period. The export figures for 2023-24 estimate 28732 metric tons, valued at approximately Rs. 6000 crores. Major importers of these vegetables from India include the USA, China, Vietnam, the Netherlands, Bangladesh, the UAE, the U.K., Malaysia, and Saudi Arabia. Additionally, a significant quantity of spices is utilized domestically for cooking and various medicinal applications. Notably, the USA and the United Kingdom rank as the top importers of chillies and onions from India. These statistics highlight the economic significance of vegetables both in India and worldwide. India continues to be the foremost producer and consumer of chillies and onions. The harvesting process for onions and chillies is contingent upon their maturity and intended use. Typically, onions, chillies, and brinjals are planted using traditional approaches, such as manual techniques involving different types of spades, forks, or bullock-drawn plows. Initially, the soil is worked manually, and the seeds are sown by hand. These traditional methods are time-consuming, labor-intensive, and often lead to uneven planting, losses, and low field capacity. Generally, seeds are sown at a depth of 2 to 3 cm and then covered with a thin layer of soil, followed by watering. Subsequently, the beds are covered with grass or sugarcane leaves to maintain the necessary temperature and moisture levels. Additionally, the increasing scarcity of skilled labor for harvesting and rising harvesting costs during peak seasons have made it challenging for farmers. Therefore, there is a pressing need to develop mechanical solutions for digging onions, chillies, and brinjals. Currently, India lacks an effective, lightweight, and affordable digger or harvester that can be utilized efficiently for various crops such as onion, turmeric, chilli, brinjal, and potato. Hence, it is essential to introduce a machine capable of digging these crops, thereby minimizing digging time, reducing human effort, and enhancing mechanization at the farmer's operational level. Considering these factors, we propose an automatic five-bar linkage mechanism to facilitate more efficient digging and seed planting in less time.

2. LIERATURE REVIEW

Jiawei Shi, Jianping Hu,Jing Wang, Wei Liu,Rencai Yue and Qian Zhang [1] discussed the design and experiment of an automatic transplanter specifically for densely planted vegetables, detailing a novel eight-row duckbill planting mechanism, its kinematic model, and performance tests, achieving a planting qualification rate of 96.62% and efficiency of 7135 plants/h.
S. M. Ishizaki Discussed [2] about a low-cost, high-efficiency automatic vegetable transplanter adapted from a rice transplanter, enhancing transplantation speed and success rates for cabbage seedlings.

Amit Ray discusses [3] about a mechanized solution for transplanting vegetable seedlings, addressing labor intensity, uniformity, and spacing challenges, while enhancing efficiency and ergonomics in agricultural practices.

Asano and Takanori Fukao [4] Discussed on the development of an automated transplanter using LiDAR for self-localization and robust control methods, addressing labor shortages in agriculture by enabling accurate transplanting of vegetable seedlings, specifically cabbage.

Gaudencio Grande [5] analyzed the advancements in automated transplanters, focusing on their physical-mechanical properties and control systems, achieving efficiencies over 90% and error rates below 7.6%.

Omkar Kakade and Gopal U. Shinde [6] Discusses the advancements in vegetable transplanting technologies, emphasizing the need for automation to improve efficiency and reduce labor intensity. It highlights opportunities for developing automated seedling pickup and drop mechanisms using robotics in vegetable transplanting operations.

Naveen Kumar C [7] Reviewed the semi-automatic vegetable transplanters, discussing their metering mechanisms, power sources, and efficiencies. It highlights their advantages over traditional methods, including improved transplanting rates, field capacity, and efficiency, ultimately enhancing production quality while saving time and costs.

Ankit Sharma and Sanjay Khar [8] discussed the development of a semi-automatic vegetable transplanter prototype for small landholdings, focusing on its design, functionality, and preliminary field testing results, highlighting its potential for enhancing vegetable production in contemporary agriculture.

Pan Zhiguo ,Yang Ranbing and Gao Huade [8] Discusses about a full-automatic transplanter designed for vegetable transplanting, featuring mechanisms for seedling delivery, clamping, and transplanting, which enhance efficiency, reduce manual labor, and minimize seedling damage during the transplanting process.

3. METHODOLOGY

This study presents a systematic approach to designing, developing, and evaluating a Five-Bar linkage mechanism for an automated vegetable transplanter to address the inefficiencies of manual transplantation processes

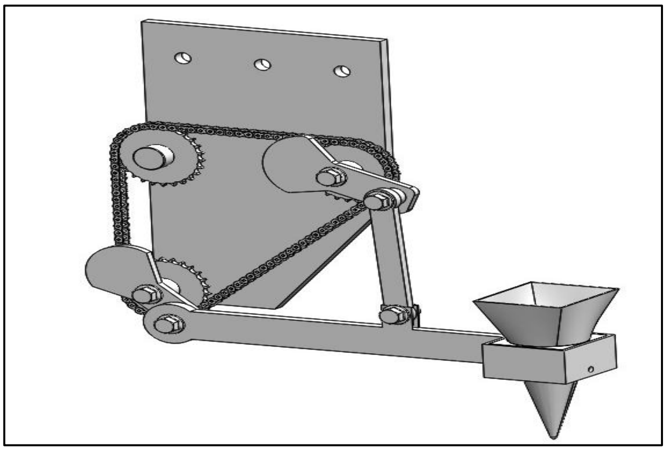

FIGURE.3.(A) *3D MODEL OF FIVE-BAR LINKAGE SYSTEM*

DESIGN REQUIREMENTS FOR PLANTING MECHANISM

The design requirements for a five-bar linkage planting mechanism include ensuring consistent planting depth, uniform seed spacing, and smooth, precise motion to achieve optimal seed placement. It must minimize power consumption and provide accessible maintenance features to enhance reliability and operational efficiency. We started with the standard values and based on the works of other types of digging mechanisms. So, the planting mechanism should have the following requirements

a) The planting depth should be around 200-300 mm based on various saplings
b) The plating space should be between 300-800 mm depending on type of plant and soil conditions
c) The transplanting rate should be around 60 – 80 plants/min
d) The angle of seedling and vertical axis of center hole of the hopper should be less than 10 degrees.
e) At point 1, the hopper needs to be stationary to receive the seedling

f) At point 2, the speed of the hopper must be at zero when dropping to align the seedling perfectly

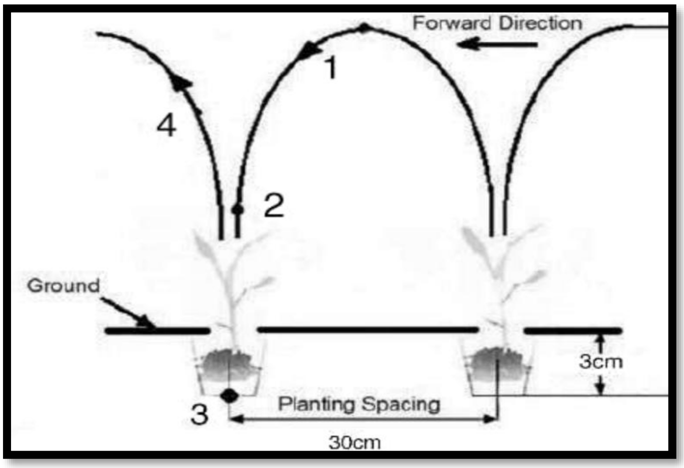

FIGURE.3.(B) *TRAJECTORY OF PLANTING MECHANISM*

Where the representation of the points is,

1 - seedling pickup

2 - hopper opening

3 - seedling drop

4 - Hopper closing

4. WORKING OF THE PLANTING MECHANISM

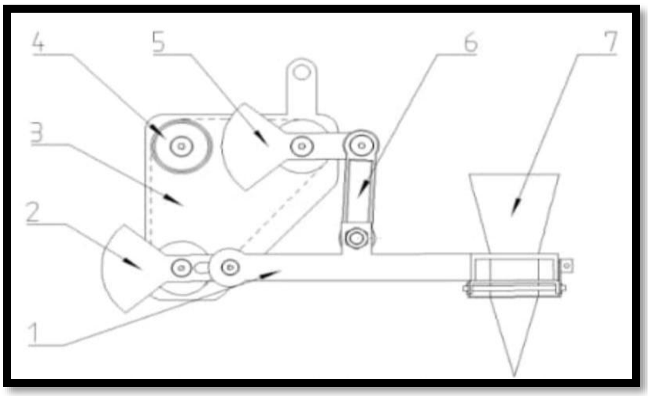

FIGURE.4.(A) DESIGN OF FIVE-BAR LINKAGE MECHANISM

As illustrated in Figure 4A, 1 - Connecting rod, 2 - lower crank, 3 - Base plate, 4 - Chain sprocket, 5 - upper crank, 6 - linkage, 7 - Hopper, the Five-bar linkage planter mechanism primarily consists of a fixed plate, chain sprocket, cranks, connecting rods, hopper, and connector. The chain transmission system activates the two crankshafts, the lower crank, and the upper crank, causing them to rotate in a clockwise direction at the same speed around their respective fixed points on the plate. The rotation of the crankshafts drives connecting rod 1 and connecting rod 2, allowing the hopper to follow a specified trajectory. The hopper, which is linked to the mechanism, is responsible for picking up the seedlings. At the peak of the trajectory, the hopper collects the seedling, and as the mechanism descends to ground level, a cam-connector system manages the hopper's opening. When it reaches the lowest point in its motion, the hopper releases the seedling into the soil. After the planting mechanism has moved away from the seedling, the hopper closes, initiating the cycle anew.

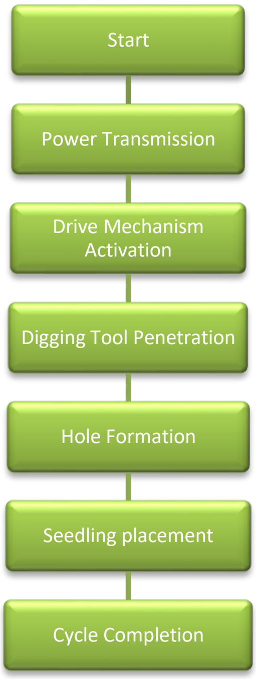

FIGURE.4.(B) *FLOW CHART OF PLANTING PROCESS*

5. DESIGN AND DRAFT OF THE HOPPER UNIT

The Hopper Structure Uses lightweight and durable materials i.e. aluminum - EN24 for resistance against corrosion and mechanical wear. IT IS Shaped in a Tapered and funnel-shaped hopper for smooth seedling flow without clogging. The Seedling Flow Control contains an Incorporate adjustable flow control gates or a metering mechanism to manage the delivery rate. The Interior surfaces are designed smooth to the reduce friction and prevent damage to seedlings. The hopper is securely mounted and aligned with the linkage system, ensuring the digging blade's operation synchronizes with seed delivery.

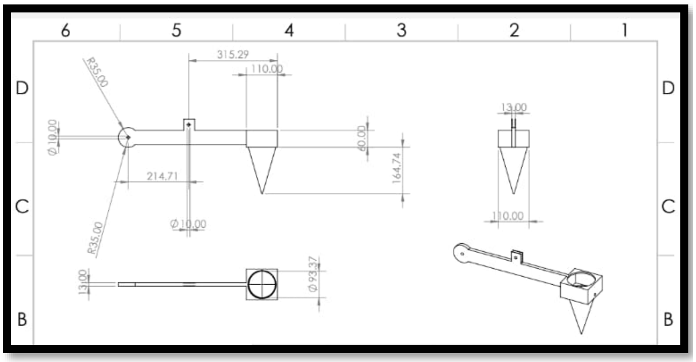

FIGURE.5 *DRAFT OF HOPPER UNIT*

Enough space is maintained for the flow of seedlings without any damage. It also Ensures the outlet of the hopper aligns with the 45 mm throat clearance to provide a clear path for the seedling deposition. the hopper unit is designed to accommodate 150 mm of blade depth adjustment, ensuring seed placement matches the planting depth. the hopper mounting system is designed to maintain a 70-degree rack angle, for tilt adjustment and optimizing the flow dynamics for seedling discharge.

6. ASSEMBLY OF PLANTING MECHANISM

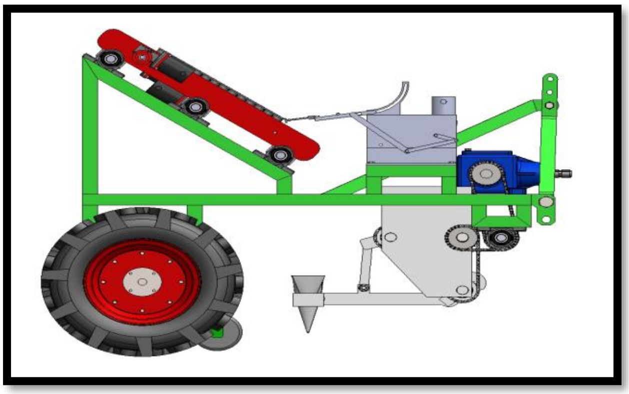

FIGURE.6.(A) *SIDE VIEW OF DIGGING SYSTEM ASSEMBLY*

The digging system i.e. the five-bar linkage mechanism is attached directly to the frame with the fixed plate of the planting mechanism, here the power is mainly directed from the PTO shaft at speed of 540 rpm which is subsequentially reduced to 72 rpm through a series of chain sprocket and shafts . which helps in the effective running of the mechanism to perfectly attain the desired results for planting of the seedling as per the predetermined plant spacing length. This system is attached with the closure system , which consists of 2 tapered wheels of

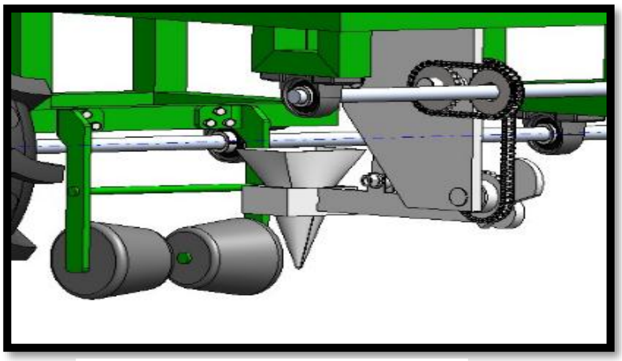

FIGURE.6.(B) *5-BAR LINKAGE MECHANISM*

tapered about 30 degrees which are aligned vertically and to follow the seedling path to close the soil behind.

7. CALCULATIONS

Bending Stress:

Outer diameter (D_o) = 50mm

Thickness = 25mm

$D_i = D_o - 2t$

$= 50 - (2 \times 2.5)$

$= 50 - 5$

$D_i = 45$ mm

$I = \pi/64\ [D_o^4 - D_i^4]$

$= 3.14/64\ [50^4 - 45^4] \times 10^{-12}$

$= 3.14/64\ [6250000 - 4100625] \times 10^{-12}$

$= 0.0490625\ [2149375] \times 10^{-12}$

$I = 105453.7109 \times 10^{-12}$

Bending strength:

$S_b = S_y\ I / C$

S_y = yield strength = 365 mpa

$= 365 \times 10^6\ N/m^2$

$C = 50 / 2 = 25mm = 0.025$ m

$S_b = (365 \times 10^6 \times 105453.7109 \times 10^{-12}) / 0.025$

$= 38.49060448 / 0.025$

$S_b = 1539.624179\ N/m^2$

Vertical Bending Stress:

Factor of safety (N/mm^2) = Tensile strength / Von mises

= 440 / 211.7

FOS = 2.07

Transverse Bending Stress:

Factor of safety (N/mm^2) = Tensile strength / Von mises

= 440 / 183.6

FOS = 2.39

8. RESULT AND DISSCUSION

The field trial of the developed digger was conducted at Sri Sairam Engineering College West Tambaram, Chennai, Tamil Nadu, India for seedlings. While testing, the digger was installed on level ground. The machine was run at no load to ensure that each component of the digger was working properly. The soil character was laterite, and both crops were sown on the ridge of size 74 cm at bottom and 33 cm at top. The irrigation was given by the inline drip system. At the time of digging, average moisture content was found 12.60 % and 11.97 % on dry basis. The tractor-drawn digger was evaluated with 20 hp New 2-cylinder 702 cc engine powered tractor manufactured by us. The performance of the digger was found to be satisfactory in respect of the digging efficiency and the measurements of the linkages achieved that proved to satisfactory are **L1=300mm, L2=106mm , L3=120mm , L4=220mm, L5=75mm**. These results achieved for the cranks, connecting rod and linkages were tested using trial and error method for the prototypes

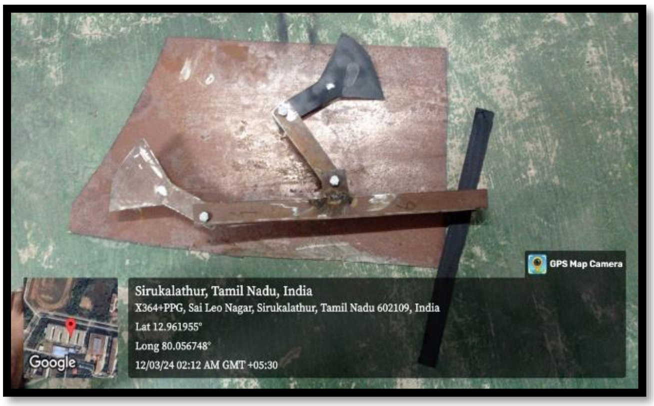

FIGURE.8 *PROTOTYPE 5-BAR LINKAGE MECHANISM*

9. CONCLUSIONS

A fully automated 5-bar linkage mechanism powered by a tractor was designed and created for an automatic vegetable transplanter. This planting system has demonstrated high efficiency and adaptability for a variety of seedlings. Its capability to produce precise and customizable motion paths guarantees consistent performance in the processes of digging, planting, and covering. By integrating adjustable features like planting depth and spacing, the mechanism is customized to satisfy the varying requirements of different crops. The design's compact size, durability, and ability to integrate with auxiliary components such as hoppers and seed metering systems make it a perfect choice for contemporary farming. With appropriate material selection based on the crops, a strong structural design, and comprehensive testing, the five-bar linkage mechanism can significantly improve productivity, accuracy, and dependability in farming operations

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