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CLUB OF BOLOGNA

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[F] PhD Extended Abstract Form *[Please, to fill out use Calibri 10 typeface])*

DEVELOPMENT OF A SELF-PROPELLED WALK-BEHIND TYPE SINGLE ROW ELECTRIC CABBAGE HARVESTER

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Extended Abstract

[12000 characters max, spaces included . It is possible to include photographs, tables, and graphs]

1. Introduction

Cabbage is an important vegetable crop that is rich in variety of minerals, vitamins and antioxidants. India is the second-largest cabbage producer globally, following China. But the conventional method of harvesting cabbage by the Indian farmers is using manual techniques employing a knife or a sickle. This tedious process exposes workers to a variety of biomechanical stresses that affect the back, neck, and upper and lower extremities, resulting in musculoskeletal disorders.

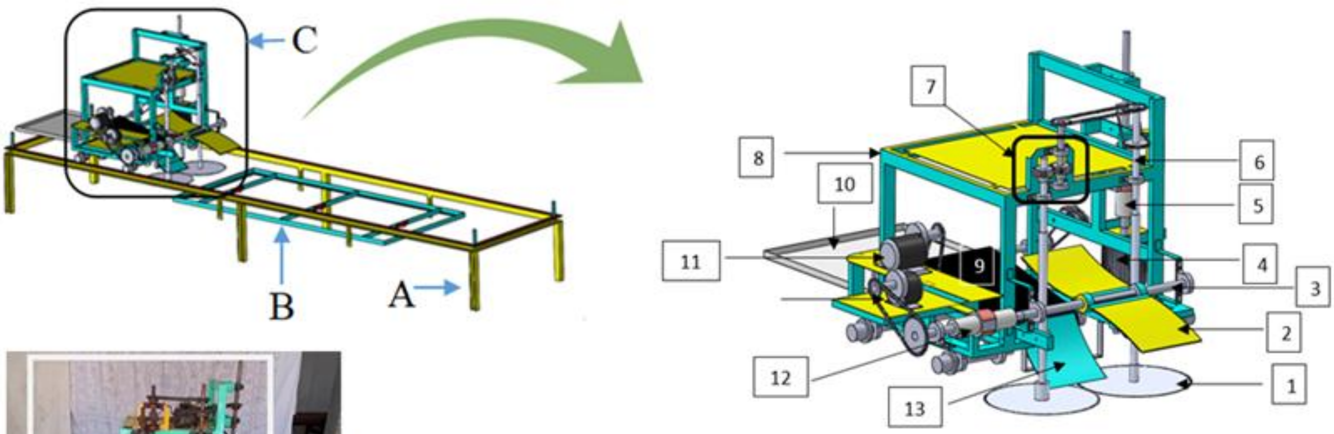
The commercial cabbage harvesters available in foreign markets are often characterized by substantial initial costs and high operational expenses, making them best suited for large-scale farming operations. The fragmented landholding pattern prevalent in Indian agriculture makes it difficult for operating those large cabbage harvesters. Further, these harvesters are typically powered by conventional fossil fuels, which, is a burden to the finite fossil fuel resources and contribute to environmental degradation, as evidenced by emissions of Nitrogen oxides (NOX) and diesel particulate matter. The escalating costs of fossil fuels and their limited accessibility in rural areas pose significant challenges to the continued use of these fuels for agricultural mechanization.

Considering the above factors, an attempt was made to develop an electric cabbage harvester that is suitable for small and marginal lands with minimum labor and power requirements and damage to the cabbages. This research was undertaken with five objectives :

I. To develop a laboratory setup for measuring the power requirements of a counter-rotating disk-type cutting unit for cutting cabbage heads.
II. To study the effect of operational parameters of the cutting mechanism of cabbage harvester under controlled laboratory conditions and to optimize these operating parameters for minimizing the power requirement.
III. To develop a deep learning-based cabbage detection system to reduce damage to cabbages during conveying.
IV. To design and develop a field prototype of a walk-behind type self-propelled electric cabbage harvester with a vision system.
V. To evaluate the performance of the developed walk-behind type self-propelled electric cabbage harvester in field following the optimized combination of operating parameters and its economic analysis for harvesting of cabbage.
VI. To accomplish these objectives, the research was carried out in five stages.

2. Development of a laboratory setup

In the first stage of research, a laboratory setup was developed considering various physical and agronomic properties of cabbage, that could simulate the actual field condition of cabbage field. The setup consisted of a main frame (A), a plant holding frame (B) and a processing trolly (C). In the plant holding frame, cabbages were clamped with the help of semi-circular clips. Provision was made to loosen and tighten the clips to accommodate different sizes of cabbage stems. The processing trolley moved on the main frame. It comprised a cutting unit, a pushing unit and a storage tray. In the cutting unit, two counter-rotating serrated disks were used. The cutter shafts were powered by a 48 V 850 W DC motor through a chain and sprocket transmission. A counter rotating mechanism comprising two same sized spur gears was installed. Four 12 V 12 Ah batteries were connected in series to power the DC motor for cutting. In the pushing unit, two pusher plates were mounted 180º apart on a pusher shaft that was powered by a 24 V 250 W DC motor through chain and sprocket transmission. Two 12 V 12 Ah batteries were connected in series to supply power to the DC motor for pushing and lifting the cut cabbages to the conveyor belt with the help of pusher plates after getting cut. The conveyor belt moved the cut cabbages to the storing tray. The propelling shaft of the processing trolley was powered by a 24 V 650 W DC motor through chain and sprockets. For powering this motor, two 12 V 12 Ah batteries were connected in series. Suitable speed reduction was employed to achieve the forward speed of the processing trolley. Power was transmitted to the shaft of the conveyor belt from propelling shaft through chain and sprockets. Speed of all the DC motors used in the laboratory setup were controlled by DC motor controllers. Two torque transducers (HBM T22/100) were used independently to measure torque required for cutting and pushing the cut cabbages.



1. Cutting disc, 2. Curved plate for pushing, 3. Pusher shaft, 4. DC motor for cutting, 5. Torque transducer for cutting torque, 6. Cutting shaft, 7. Counter-rotating arrangement, 8. Frame, 9. Conveying belt, 10. Tray, 11. DC motor for propelling and conveying, 12. Torque transducer for cutting torque, 13. Inclined plate

Fig. CAD model of laboratory setup

Fig. Laboratory experiment and data acquisition system

3. Optimization of operating parameters

In the second stage of the research, laboratory experiments were carried out with Pusa Mukta cabbage variety in the developed setup. Forward speed, cutting speed and cutting height were considered as independent variables, while torque required for cutting and pushing was considered as the dependent variable. The uprooted cabbages from the field were clamped in the plant holding device and the processing trolley of the developed laboratory setup was then made to move at the desired cutting speed, forward speed and cutting height. The main goal of this study was to obtain the optimum values of those input parameters for minimum power requirement with a smooth harvesting operation. The range of cutting speed, forward speed and cutting height from the bottom of the cabbage head were selected as 400 rpm to 600 rpm, 0.22 m/s to 0.32 m/s and 0 cm to 2 cm, respectively. For deciding the experimental run, three-factor three-level full factorial design was. Before the experiment, the torque transducers were calibrated and a QuantumX data acquisition system was used to store the real time torque data. Data obtained from the laboratory experiments were studied, analysed and Analysis of Variance (ANOVA) was carried out. The power requirement for cutting and pushing was calculated for each combination of independent variables. Response surface methodology (RSM) was used for optimizing the input parameters for minimum power requirement for cutting and pushing cabbages. The interaction effects of different input parameters were studied in 3D surface plots and contour plots. The optimized operating parameters were found at a cutting speed of 590 rpm, forward speed of 0.25 m/s and cutting position of 1 mm.

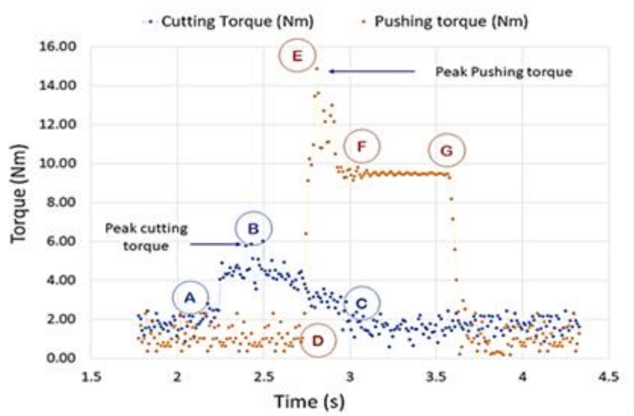


Fig. Real time torque data

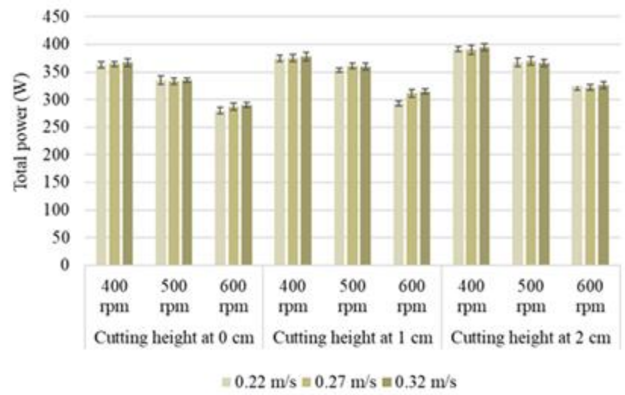


Fig. Variation of total power requirement

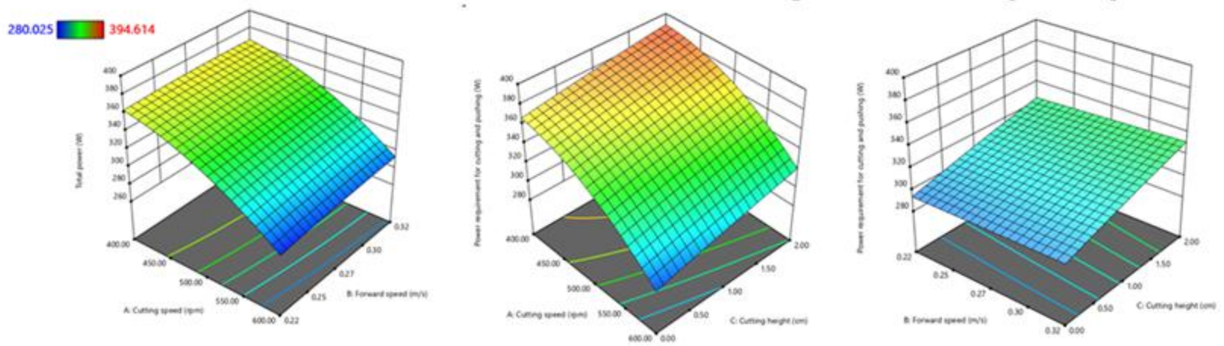


Fig. Optimization of power requirement

4. Development of deep-learning based cabbage pushing system

In the third stage of research, a custom cabbage detection model was developed with YOLOv8. The images of cabbages across different varieties were collected. The images were augmented in terms of rotation, flip and brightness to get a greater number of images. The images were annotated with bounding boxes using the LableImg tool and 'cabbage' class was assigned to the bounding boxes in the images. The custom dataset containing 1289 images with 2113 cabbage heads was trained in Google Colaboratory notebook with the same training settings as YOLOv8. The precision, recall, F1 score, and mean average precision (mAP@0.5) of the trained model were evaluated to determine its applicability for the detection of cabbages. The developed model was implemented in the Nvidia Jetson Nano, a single board computer capable of operating deep learning models. The Jetson Nano was equipped with a 60 fps Logitech Brio Stream Webcam. Frames were captured by the camera as the harvester advanced. The YOLOv8 detection algorithm was executed by the Jetson Nano, which also processed the frames captured by the camera. The Arduino Uno microcontroller and the Jetson Nano communicated via serial communication. This microcontroller was employed as an interface to regulate the plunger mechanism in accordance with the detection results obtained from the Jetson Nano. In order to facilitate communication between the Jetson Nano and the Arduino Uno, as well as to interface with the stepper motor driver (DM556), the requisite electronic circuits were implemented.

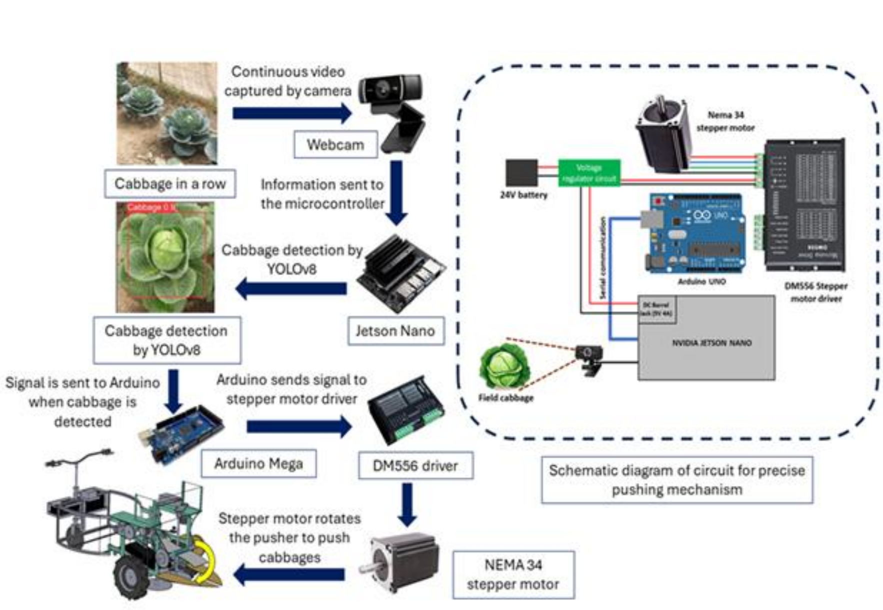


Fig. Precise cabbage pushing mechanism

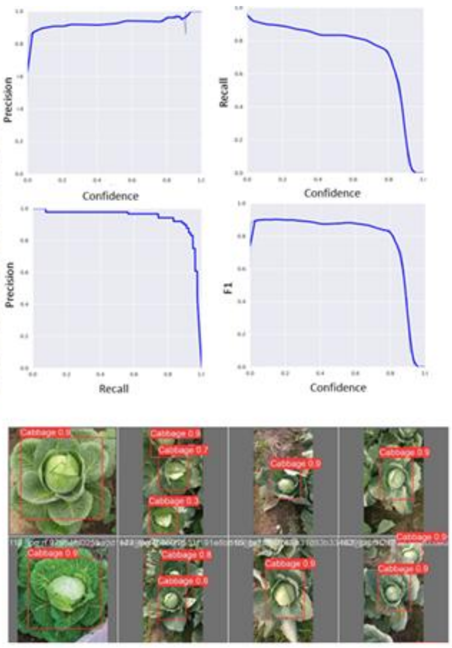


Fig. Performance of the developed YOLOv8 detection model

5. Structural analysis and development of field prototype

In the fourth stage of research, the field prototype of an electric cabbage harvester was developed taking into consideration the findings from the laboratory tests. Calculations for required motor size, speed reduction, maximum moment induced in the shafts, battery sizes were carried out. The dimensions of the critical components of the designed harvester such as cutter shaft, pusher shaft and propelling shaft were set after calculation and were checked for safety using finite element analysis (FEA). After that, the prototype was fabricated at the workshop of Agricultural and Food Engineering Department, IIT Kharagpur. The developed harvester had an overall dimension of 2571×880×742 mm with a total weight of 176 kg. It was a three-wheeled harvester, two pneumatic wheels for propelling at the front and one rigid wheel at the rear for steering. It comprised a cutting unit, pushing unit, conveying unit, propelling unit, storage bin, and a handle. A 48 V 850 W DC motor was used to power the cutting unit of the harvester. A stepper motor (NEMA 34, 130 kg-cm torque) powered the pusher shaft. A 24 V 650 W DC motor was used to propel the harvester and convey the cut cabbages to the storage unit. Four 12 V 18 Ah lead-acid batteries were connected in series for powering the DC motor for cutting. Two 12 V 18 Ah lead-acid batteries were connected in series for powering the DC motor for propelling and conveying.

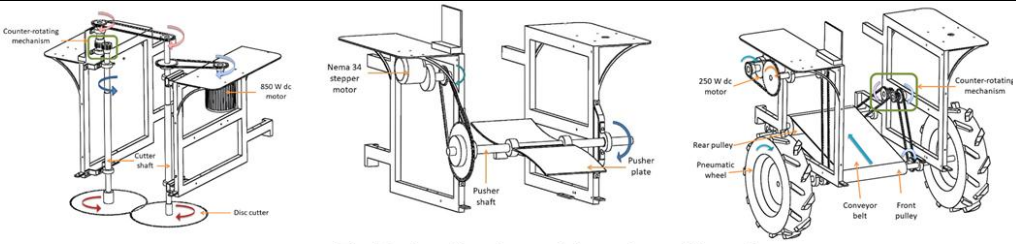


Fig. Design of cutting, pushing and propelling units.

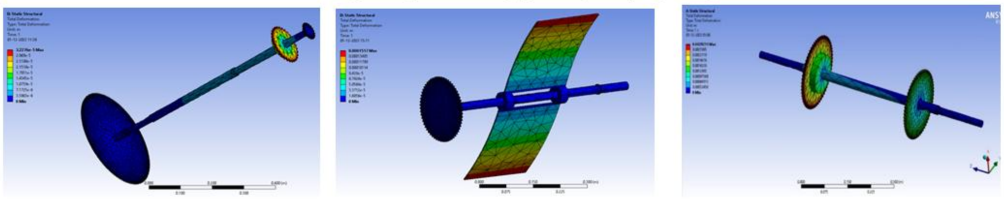


Fig. 14 Structural analysis of critical components

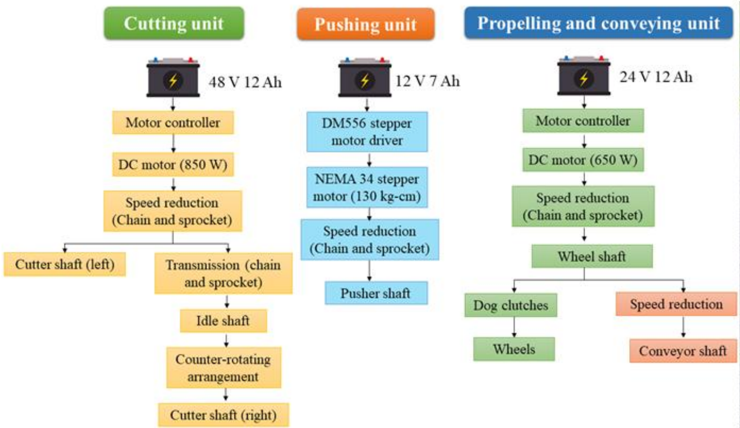


Fig. Electric power distribution

Fig. Developed prototype

6. Field performance evaluation of electric cabbage harvester

In the last stage of research, the performance of the developed electric cabbage harvester was evaluated in a polyhouse (12×4 m) as well as in the field (40×20 m) with three replications. Instantaneous power consumption (IPC), cutting quality of cabbages, field capacity, and field efficiency were measured during testing. The cut cabbages were classified into four categories, namely: accurate cutting, insufficient cutting, split cutting, and excessive cutting. Cutting efficiency and harvesting losses were computed from the above classifications. IPC of the cabbage harvester during operation was measured from the battery output. For this purpose, a separate circuit was made consisting an Arduino Mega, three digital voltmeter ammeter, three 70 A shunt resistor, three micro-SD cards and module. The maximum IPC was measured as 978.64 W. The turning radius was measured and accordingly the plan of path in the fields test was decided. Time taken for harvesting, turning, and unloading were measured using stopwatch. From those data, the actual field capacity and field efficiency were computed as 0.029 ha/h and 54.86%, respectively. In order to ensure the safety of the operator ergonomically, both noise and vibration were measured. The noise at the operator and bystander's positions was measured as per IS 12180 (2000) part 1 and 2, using a sound level meter. A hand vibration analyzer was used to measure the vibration in three dimensions on the handle harvester. The measured A(8) value of hand vibration for the cabbage harvester was found to be 2.26 m/s2 and it was lesser than the acceptable limit of 7.5 m/s2. The measured noise levels were 74.5 dB(A) at the operator's ear level and 52.8 dB(A) at a distance of 7.5 m from the harvester. Both the values were lesser than the acceptable limit of 90 dB(A). At the end, the economic analysis of the harvester and its comparison with manual harvesting were carried out considering its fixed cost and variable cost. The total cost of harvesting cabbages with the developed harvester was computed as Rs. 9143.51 (77.42 $) per ha. The operational cost with the developed cabbage harvester was found to be 26.85% lower than traditional harvesting method. The break-even point of the developed cabbage harvester was calculated as 6.07 ha/year. Moreover, the use of the developed harvester reduced the labor requirement by 58.5% as compared to manual harvesting of cabbages.

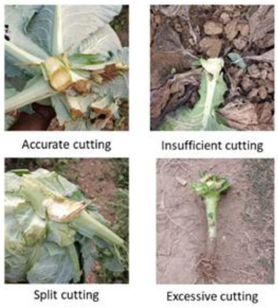


Fig. Types of cutting

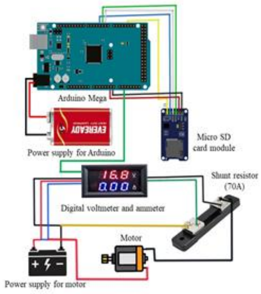


Fig. Measurement setup for power consumption

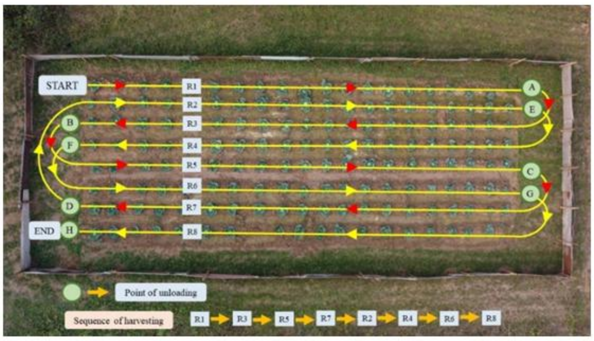


Fig. Field testing of developed cabbage harvester

Fig. Measurement of noise

Fig. Measurement of vibration

Final remarks concerning benchmarks and strength points of the the Pellizzi Prize 2026

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This thesis can be classified within category 1.2 Agricultural Machines and Mechanization. The developed cabbage harvester was capable of cutting, pushing, conveying, and storing the cut cabbages with a minimal power requirement. The utilization of electric batteries has resulted in the elimination of environmental pollution, rendering it more advantageous than the current cabbage harvesters that have IC engines. Using YOLOv8 cabbage detection model in precise cabbage pushing system, the mechanical damage has been reduced significantly. The system is well suited for small and marginal cabbage growers, providing economic viability and environmental sustainability.

The most remarkable impacts of the work are 8 peer-reviewed publications, 1 national level Gold Medal, 1 patent application and 1 copyright application. All publications were in journal of primary importance in the field of agricultural technology and cleaner solution.