Abstract

To replace the traditional manual cabbage harvesting method commonly practiced by Indian farmers, a self-propelled walk-behind electric cabbage harvester was developed at the Agricultural and Food Engineering Department, IIT Kharagpur. The key concept was to cut the cabbage head from its stem and push the cut cabbage head to a storage unit with the help of a real-time vision-based precise cabbage pushing mechanism. Prior to developing the field prototype, a laboratory setup simulating actual field conditions was developed considering the dimensions and physical properties of Pusa Mukta cabbage variety. The setup consisted of a main frame, a plant holding frame and a processing trolly. Two counter-rotating disks cut the cabbage heads, clamped in the plant holding frame, from their stems. A pusher plate pushed the cut cabbages to the conveyor belt, which then moved the cut cabbages to a storage bin. Full factorial design was followed in the laboratory experiment and torque required for cutting and pushing were measured. Optimization was carried out to minimize the power requirement for cutting and pushing. 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. A custom cabbage detection model was developed with YOLOv8 and deployed in the Nvidia Jetson Nano to develop a vision-based, precise cabbage-pushing mechanism. The custom cabbage detection model achieved an F1 score of 0.90 at a confidence of 0.149 and a mAP@0.5 of 0.938. The Jetson Nano used serial communication with an Arduino Uno microcontroller to interface with the stepper motor driver (DM556) that rotated the pusher plate. Based on the optimized operating parameters obtained from laboratory tests, a field prototype was designed in SolidWorks 2016. It comprised a cutting unit, pushing unit, conveying unit, propelling unit, storage bin, and a handle. Finite element analysis of critical components such as cutter shaft, pusher shaft and propelling shaft was carried out in ANSYS software. The developed harvester had an overall dimension of 2571×880×742 mm and total weight of 176 kg. A 48 V 850 W DC motor was used to power the cutting unit of the harvester. The pusher shaft was powered by a stepper motor (NEMA 34, 130 kg/cm torque). 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 to power the DC motor for cutting. Two 12 V 18 Ah lead-acid batteries were connected in series to power the DC motor for propelling and conveying. The performance of the developed cabbage harvester was evaluated in a polyhouse (12×4 m) and in the field (20×8 m) with three Indian cabbage varieties i.e., Pusa Mukta, Pusa Drumhead and September Early. The developed harvester had a working width of 0.6 m and when operated at a forward speed of 0.25 m/s, the actual field capacity and field efficiency were found to be 0.029 ha/h and 54.86%, respectively. Instantaneous power consumption (IPC), cutting quality of cabbages, field capacity, field efficiency, noise and vibration produced by the harvester were measured during testing. The values of cutting efficiency were found to be 72.5% for Pusa Mukta, 77.5% for Pusa Drumhead, and 67.5% for September Early, in polyhouse testing as compared to 80%, 79.59% and 74% in field. Harvesting losses ranged from 6.67% to 10.204%. The maximum instantaneous power consumption for cutting, pushing, conveying and propelling was calculated to be 948.53 W and 978.64 W in the polyhouse and field, respectively. The measured A(8) value of vibration for the cabbage harvester was found to be 2.09 m/s^2 in the polyhouse and 2.26 m/s^2 in the field and was lesser than the acceptable limit of 7.5 m/s^2. The measured noise levels were 78 dB(A) at the ear level of the operator and 56 dB(A) at a distance of 7.5 m from the harvester in the polyhouse, as compared to 74.5 dB(A) and 52.8 dB(A) in the field. Both values were lesser than the acceptable limit of 90 dB(A). The operational cost with the developed cabbage harvester was 26.85% lower than traditional harvesting methods. The break-even point of the developed cabbage harvester was calculated as 6.43 ha/year. Using the developed harvester reduced labor requirements by 58.5% compared to manual harvesting of cabbages.

Keywords: Electric farm implements; Cabbage harvesting; Optimization; Deep-learning; Instantaneous power consumption; Cutting quality; Field efficiency.