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Performance evaluation of a lowland cabbage harvester prototype

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Abstract

In Malaysia, round cabbage was planted in an area of 3,424 ha and 80,641 MT was produced in 2020. The shortage of workers is a major issue in large-scale cabbage cultivation. The most tedious and costly part was during the harvesting period since more workers were required. This article explained a modification and performance evaluation of a lowland cabbage harvester prototype. The prototype was designed and developed by MARDI in 2020. However, a few modifications were required to enhance the performance and efficiency of the developed prototype. A mechanism, which was called the reel system, was designed to ensure increased harvesting efficiency. The reel functioned as a puller mechanism to make sure the harvested cabbage was pulled smoothly to the conveyor system. The reel system also prevented the harvested cabbage from becoming stuck in the two cutting blades. It was driven by a 12V electric motor with 200W of power and connected to a gearbox, chain, and sprocket to increase the torque delivery. An evaluation performance test was carried out and the results showed that the effective field capacity was 0.065 ha/hr, with an average speed of 0.54 km/hr and 60.2% machine field efficiency. Only 14.4 man-hr/ha was required for the cabbage harvester while manual harvesting required 28.9 man-hr/ha. This represents a labour saving of about 50% when using the cabbage harvester.

1. Introduction

The Cannonball cabbage or round cabbage, which belongs to the Brassicaceae family, is ideally cultivated in temperate and subtropical areas (Peter and Hazra., 2015). Round cabbage was planted on an area of 3,424 ha and 80,641 MT was produced in 2020. Pahang led the production of cabbage, with 71,988 MT of the total yield produced in Malaysia (Jabatan Pertanian Malaysia, 2020).

Demand for cabbage in Malaysia amounts to almost 215,043 MT. Therefore, Malaysia imports cabbage, mainly from China and Indonesia, to meet the demand in the local market. Based on statistics from 2020, the self-sufficiency ratio (SSR) of round cabbage was 37.5% and its import dependency ratio (IDR) was 63.6%, with cabbage imported to meet the local demand (Department of Statistics Malaysia, 2020).

Malaysia has started to use lowland crop technologies for cabbage, which may minimise the reliance on imports. Lowland cabbage is important to support the production of local highland cabbage growers (Ibrahim *et al*., 2019). The temperate environment is not an issue in cultivating round cabbages in lowland regions since a suitable variety of seeds has been introduced to fit the growing conditions, which involve slightly higher temperatures than in the highlands. Malaysia can provide 80K MT of cabbage per year through highland cultivation, but the overall supply has been projected to increase by 40% due to the latest technologies for growing cabbage in the lowlands (Mohd Fazly *et al*., 2020).

In conventional harvesting, workers use sharp knives to cut the cabbage stems. The harvested cabbages are collected manually and put into baskets. This process is very tedious and costly since more workers are required.

A shortage of workers is a major issue in large-scale cabbage cultivation. Each cabbage farmer has a problem during harvesting because it is a very high-cost activity (Rezahosseini *et al*., 2019). Harvesting activity accounts for almost 40% of the workload in cabbage cultivation (Wang *et al*., 2014). A mechanised alternative was required to solve the problem. If mechanisation could be

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utilised, the large area of cultivation would justify the high overheads (Glancey and Kee, 2005). Therefore, the utilisation of mechanisation in vegetable production was the best approach. Apart from reducing the dependency on conventional inputs and labour, mechanisation brings the grower increased production, as well as an improved income and standard of living when vegetables are produced on a large scale.

Many researchers have studied the harvesting of vegetables through mechanisation. One of the related technologies was the single-row Egyptian cabbage harvester with serrated-edge cutter discs, which was developed in Egypt (Ibrahim and Didamony, 2020). However, this machine had no collection mechanism since the harvested cabbage was left on the ground. In Russia, a cabbage harvester was invented that collected stacks of heads in cases on trailers (Alatyrev *et al*., 2020). This technology was tractor-powered and had to be attached in order to run the harvester. The technologies developed have used several methods of cutting and harvesting the yield.

MARDI developed a lowland cabbage prototype in 2020. As this was a prototype development, an analysis of the cabbage harvester's mechanical properties and the planting characteristics of the cabbage were considered (Mohd Fazly *et al*., 2020). MARDI decided to design and develop the harvester to come with a collector. Round cabbages were planted in a row on each bed, and the harvester developed focused on cutting the heads of the cabbages and collecting the yield from the field. However, an improvement was required for the step after the cutting blade to ensure the harvested cabbage was smoothly transported to the conveyor system.

This paper focused on the modification and performance evaluation of the lowland cabbage harvester prototype.

2. Materials and methods

2.1 Cabbage harvester

The cabbage harvester used in this study was developed by MARDI researchers in 2020. Figure 1 shows the overall dimensions of the harvester, which had a length of 3000 mm, a width of 2000 mm, and a height of 1000 mm. The harvester was attached to the side of a modified vehicle suitable for use on a farm. The developed prototype consisted of a frame chassis for carrying the whole harvesting mechanism set and a guide for the vehicle driver along each row of cabbage plants. The prototype also featured two cutting blades with contra-rotating discs for cutting the stems and leaves from the uprooted cabbage heads and a conveyor belt system to transport the cabbage heads directly into the collection basket at the back of the vehicle. The harvesting machine had an adjustable cutting mechanism. All the parts of the harvesting system were powered by an electric motor. The overall specifications of the harvester are shown in Table 1.

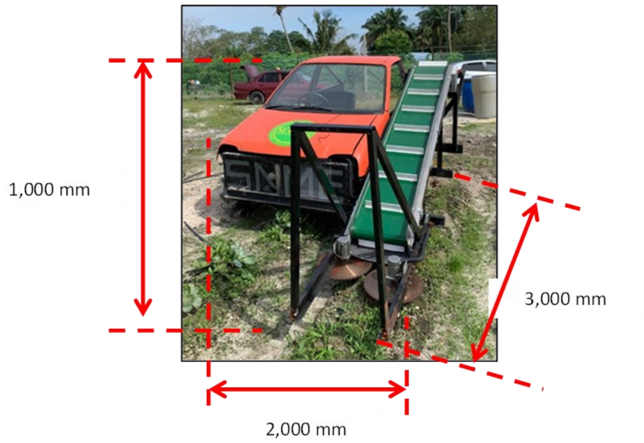

Figure 1. Overall dimensions of the harvester

Table 1. Overall specifications of the harvester

Parameter	Specification
Dimension (L × W × H) (mm)	3,000 × 2,000 × 1,000
Working width (mm)	700
Engine capacity (cc)	660
Engine type	Petrol
No. of blades	2
Weight (kg)	1,200

2.1.1 Modification

A modification was required to enhance the performance and efficiency of the developed prototype. A mechanism, which was called a reel system, was designed to ensure increased harvesting efficiency. The reel functioned as a puller mechanism to make sure the harvested cabbage was transported smoothly to the conveyor system. The reel system also prevented the harvested cabbage from becoming stuck in the cutting blades. Figure 2 shows the sketch of the additional reel system attached to the harvester.

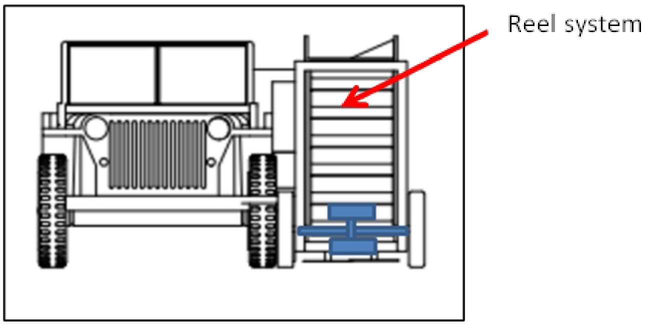

Figure 2. Sketch of the additional reel system

2.2 Experimental plot

An experimental plot was designed at the MARDI Kundang Research Station, Selangor. The cabbage was planted using a single-row technique on tin-tailing soil. The overall size of the plot was 1 ha and 10 rows were

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selected as the harvesting plot on which to use the harvester. The lowland cabbage harvesting season was around March 2022.

2.3 Performance evaluation

The Theoretical Field Capacity (TFC), Effective Field Capacity (EFC) and Field Efficiency (FE) were measured. EFC can be defined as the ability of a machine to run under actual field conditions (Zhou *et al.*, 2012). FE was defined as the percentage of time in which a machine is operated at its full rated speed and width in the field (Nasri *et al.*, 2016). FE describes how effective time is spent when doing work (Grisso *et al.*, 2014). The FE for an actual field operation is always less than 100% because of headland turns, machine trouble, the ground surface and overlapping (Zandonadi, 2012). The formulas adopted to calculate the TFC, EFC and FE were as reported by Hanna (2016).

The formulas are as follows:

$$TFC = (S \times w)/10 \quad (1)$$

where s = average speed of the machine (km/hr) and w = rated width of the machine (m)

$$EFC = A/t \quad (2)$$

where A = total area (ha) and t = total time (hr)

$$FE = EFC/TFC \times 100 \quad (3)$$

The time taken to harvest each row and the turning times were measured, while the Theoretical Field Capacity (TFC), Effective Field Capacity (EFC) and Field Efficiency (FE) were calculated.

3. Results and discussion

3.1 Machine design modification

Figure 3 shows the constructed cabbage harvester prototype with the reel mechanism. The reel consisted of four evenly shaped square rubbers and was driven by a 12V electric motor with 200W of power, and it was connected to a gearbox, chain, and sprocket to increase the torque delivery. The reel system functioned very well in terms of pulling the harvested cabbage smoothly to the conveyor system.

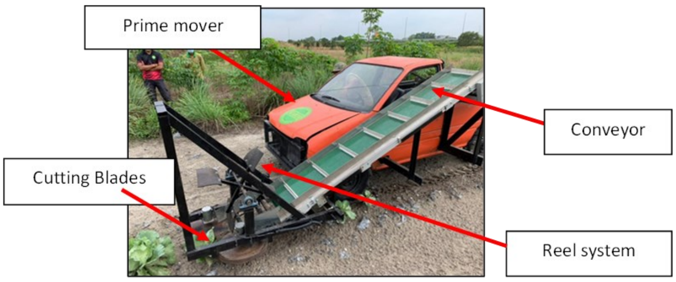

Figure 3. Constructed prototype of cabbage harvester

3.2 Machine performance and evaluation

The parameters and performance of the harvester are presented in Table 2.

In general, it took about 15.3 hrs of operation to complete the harvesting and collection of cabbage from one ha. Due to the limitations on prime mover movement, the harvester's average operating speed was minimal, 0.54 km/hr. Based on the TFC and EFC, the field efficiency was calculated to be only 60.2%. According to the evaluation, this machine can operate at 14.4 man-hr/ha, while manual harvesting requires double that, at as much as 28.8 man-hr/ha. This indicates that 50% of the labour can be saved, as well as costs, by using this cabbage harvester. The field efficiency of this harvester can be improved in the future by improving the prime mover movement.

Table 2. Machine parameters and performance evaluation

Item	Machine Parameters
Engine power (hp)	31
Area (ha)	1
Harvesting speed (km/hr)	0.54
Average harvesting time (hr/ha)	15.3
	Performance Evaluation
TFC (ha/hr)	0.108
EFC (ha/hr)	0.065
FE (%)	60.2

5. Conclusion

The lowland cabbage harvester prototype was improved and modified to increase its efficiency and performance. The development of the reel mechanism improved the machine's field efficiency. The total time required to harvest was also reduced by half, compared to manual harvesting. This would reduce the labour cost and labour shortage problem in the agriculture sector, especially for the harvesting process. In future research, it would be useful to identify harvesting losses by using this harvester prototype. Some improvements are also required to the harvester's prime mover.

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