



Design criteria for a semi-automatic cassava root cutting machine using a cylindrical saw

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doi: 10.14456/abe.2026.12

Received 13 May 2026

Revised 15 July 2026

Accepted 31 July 2026

Abstract

The purpose of this research was to compare the working capacity between farmers and a test set in the process of cutting cassava root from the stem of the Kasetsart 50 variety in the areas of Maha Sarakham and Khon Kaen provinces. This study focused on analyzing the quantitative and weight-based working capacity and the cassava flesh loss rate. The cassava harvesting process used by farmers was also studied through observation and in-depth interviews, including the study of the cassava's physical characteristics. The performance test results of the test set conclude that a cylindrical saw blade speed of 1,000 rpm and a handle descent time of 3.75 s are the most suitable criteria for designing a semi-automatic cassava root-cutting machine using a cylindrical saw blade, due to the highest rate of successful root cutting and the highest working capacity. Furthermore, the energy consumption rate and the loss rate are at a low level. When compared to the working capacity of farmers in each plot studied, the test set showed a working capacity 1.7 – 4.7 times higher than that of the farmers.

Keywords: Cassava root-cutting machine, Cassava, Design criteria for cassava root-cutting machine, Kasetsart 50 cassava variety

1. Introduction

Cassava is a vital commercial economic crop for Thailand, with an average annual production exceeding 26 million tons. Thailand is the world's leading producer and exporter of cassava, accounting for more than 70% of total global exports [1]. Although cassava is a perennial crop that can be harvested year-round, farmers typically harvest at 9–12 months to prepare the land for the next planting season [2].

Current cassava harvesting processes still rely heavily on manual labor, with each stage being labor-intensive. In particular, the process of detaching cassava roots from the rhizome (detachment/cutting) is the most physically demanding and time-consuming step [3]. The harvesting stages consist of: digging or pulling the cassava roots from the soil, detaching the roots from the rhizome, piling the roots and loading the roots onto transport vehicles [4].

Presently, harvesting methods among Thai farmers are categorized into two types are the traditional method: utilizing manual labor to dig and cut roots using hoes or basic tools and semi-mechanized method: utilizing cassava diggers to lift the roots from the ground, though manual labor is still required to detach the roots from the rhizome [5]. Manual root detachment is significantly time-consuming and labor-intensive [6]. Furthermore, the sector faces a critical labor shortage as the agricultural workforce declines due to an aging society, with the proportion of the population over 65 years old steadily increasing [7]. This has led to rising labor costs and harvest delays.

The integration of efficient agricultural machinery to replace manual labor could enable faster harvesting, reduce costs, and increase production efficiency [4]. Past research has led to the development of various cassava rhizome cutting machines, such as Langkapin et al. [8] developed cassava root strippers with a stripping efficiency of 94.5–97.9%, a capacity of 313–376 kg/h, and fuel consumption of 5.2–6.1 L/h. Cassava root cutting machines designed to study mechanical characteristics during the shearing process [9].

Cassava rhizome choppers, where key factors affecting efficiency were found to be root branching patterns and saw blade spacing [10]. Despite these advancements, some developed prototypes still face limitations, such as low efficiency compared to manual labor or a lack of practical applicability in real-world conditions [11].

Consequently, this study aims to investigate the cassava harvesting methods of farmers in Maha Sarakham and Khon Kaen provinces and to establish design criteria for a cassava rhizome cutting machine intended to replace manual labor. The ultimate goal is to provide a design framework for a high-efficiency machine that meets or exceeds the performance of manual labor and can be practically applied in the agricultural sector.

2. Materials and methods

This research focuses on a comparative study of operational performance between manual labor (farmers) and a prototype cassava root cutting unit. The objective is to evaluate performance in terms of both quantity (time-based) and weight, as well as the loss of cassava flesh during the rhizome detachment process. The data obtained serves as a basis for establishing design criteria suitable for practical applications. Field studies were conducted in Maha Sarakham province (Borabue and Kut Rang districts) and Khon Kaen province (Nam Phong), which are prominent areas for the cultivation of the Kasetsart 50 cassava variety.

2.1 Data collection

The data used in this research is Primary Data, collected directly from cassava farmers through field observations, interviews, and video recordings of actual operations in agricultural plots. This approach ensures both qualitative and quantitative data that accurately reflect the real-world working conditions of local farmers. The study population consists of farmers across four test plots (Borabue, Kut Rang, and Nam Phong). These plots feature varying planting patterns and spacing (between plants and rows) to ensure the data covers a diverse range of field characteristics and harvesting methods. The collected data includes (Table 1):

- 1) Row and plant spacing (cm): to calculate planting density.
- 2) Plot size (m²): measured via GPS to calculate the operational rate per unit area.
- 3) Cassava root weight (kg): to calculate the weight-based operational rate.
- 4) Activity logs of farmers: recording each harvesting stage, including pulling, detaching, piling, and loading.

Table 1 Main variables and objectives for data collection

Measured variables	Unit	Data collection method	Objectives
Harvesting stages	-	Observation and Interview	To record the sequence of steps and operational techniques.
Row spacing	cm	Tape measurement	To determine the planting density.
Cassava root weight	kg	Actual weighing	To calculate the weight-based operational rate.
Cassava root size	cm	Vernier caliper measurement	To specify the dimensions of the machine's feeding hopper.
Density and strength	kg/cm ³	Experimental cutting and measurement	To calculate shear force and cutting energy.

2.2 Physical properties

The cassava variety Kasetsart 50 was selected as the sample for this study. The roots were carefully harvested to prevent any physical damage and to allow for accurate measurements of diameter, length, weight, and root distribution within each row. Prior to cleaning and weighing, reference marks were made on the samples to distinguish between the above-ground and below-ground portions. The physical data obtained were used to calculate cutting forces, optimal cutting angles, and appropriate blade dimensions. These physical parameters served as critical design criteria for the machine, including:

- Root spacing: used to determine the appropriate width of the feeding inlet.
- Average root mass: used to calculate the shear force required for the cutting blades.
- Root diameter: used to optimize the rotational speed and the height adjustment of the cutting assembly.

2.3 Cassava harvesting processes

The cassava harvesting process is categorized into four primary stages as shown in Figure 1:

- Digging or uprooting: the process of lifting the cassava roots from the soil.
- Detaching: the separation of the roots from the main stalk or rhizome.
- Piling: collecting and grouping the detached roots in the field for easier handling.
- Transportation: the conveyance of the harvested roots from the field to the storage or processing site.

Working capacity were calculated in each step to calculate the working capacity (plants/h/person) according to Equation 1.

$$W = \frac{N}{T} \quad (1)$$

Where:

- W = Working capacity (plants/h/person)
- N = Number of harvested plants/person
- T = Working time (h)

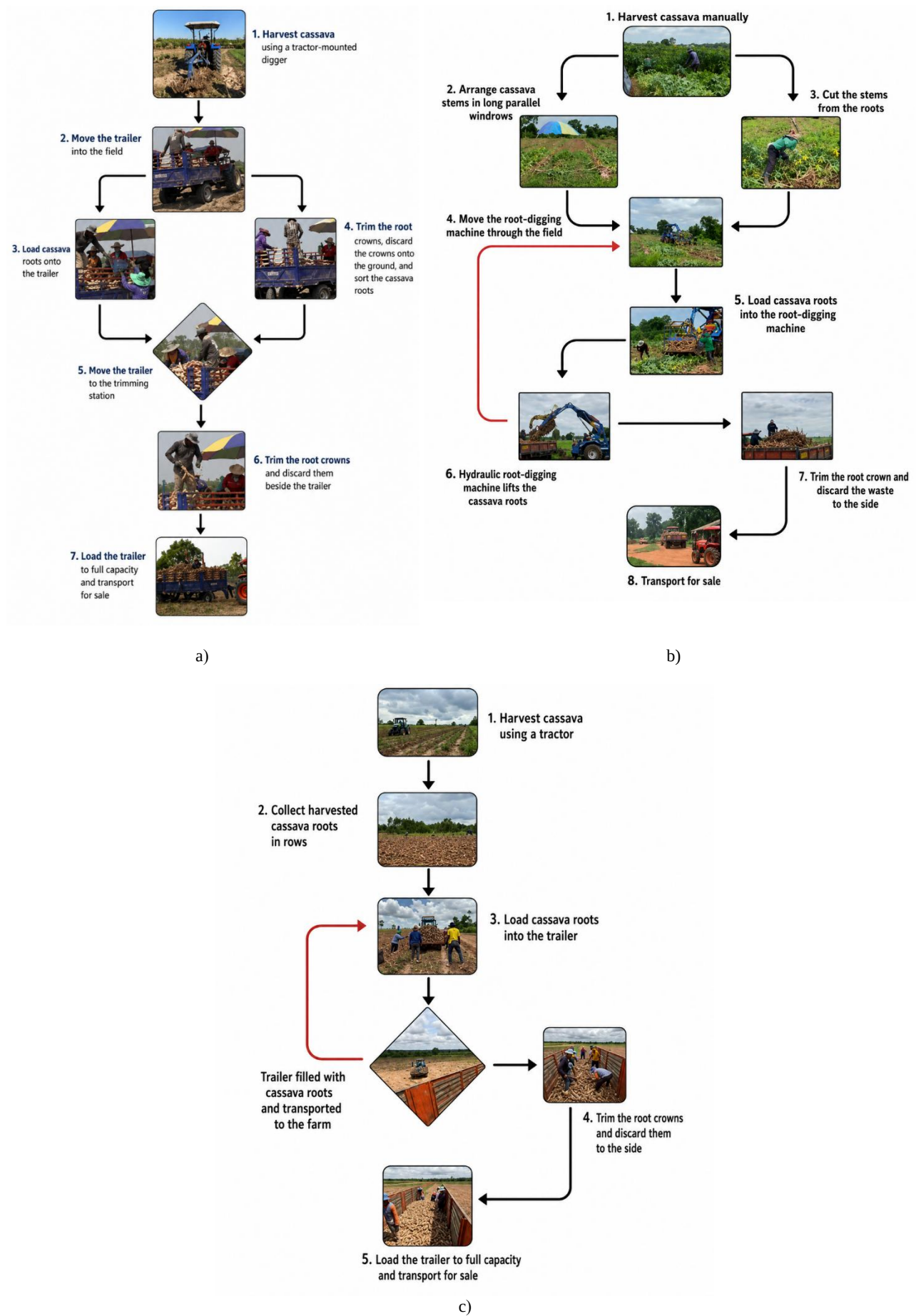


Figure 1 Cassava harvesting process in a) Nam Phong District, Khon Kaen Province, b) Borabue Districts Maha Sarakham Province and c) Kut Rang Districts, Maha Sarakham Province

Furthermore, the prototype machine's performance was evaluated in comparison to manual labor by calculating the Cutting Efficiency (E_c) using Equation 2.

$$E_c = \frac{M_c}{M_t} \times 100 \quad (2)$$

Where:

- E_c = Cutting efficiency (%)
- M_c = Amount of successfully cut material (kg)
- M_t = Total amount of material fed into the machine (kg)

2.4 Compaction labor cost

To evaluate the economic viability between manual labor and the test rig (or prototype unit), the total cost per day (Baht/day), cost per unit of product (Baht/t), and cost per area (Baht/m²) were calculated using the following Equation 3, 4 and 5, respectively.

$$C_{total} = w \times L \quad (3)$$

$$C_{ton} = \frac{C_{total}}{Y} \quad (4)$$

$$C_{rai} = \frac{C_{total}}{A} \quad (5)$$

Where:

- w = Average wage per person (Baht/day)
- L = Number of laborers (person)
- Y = Harvested yield (tons/day)
- A = Harvested area (m²/day)

2.5 Design criteria for the cassava rhizome chopper

The design of the cassava rhizome chopper was based on physical characteristics and field observations of manual labor operations. The primary design criteria considered include:

- Size and weight of the tubers.
- Canopy height.
- Distance between the handle and the cutting blade.
- Required shear force for cutting.
- Energy consumption per work cycle.
- Working capacity (plants/h, m²/h).

2.6 Testing procedures for the test rig

- Manual feeding stage: the operator feeds the uprooted cassava tubers into the feeding position. The rhizome or the "neck" area of the tuber must be aligned with the gripper mechanism to prepare for the cutting process.
- Gripper mechanism: once the cassava is fed into the system, the gripper securely clamps the rhizome to prevent slippage during cutting. The gripping force is adjusted to a level that ensures stability without damaging the rhizome tissue.
- Gripper downward motion: after securing the tuber, the gripper moves vertically toward the cylinder saw at a constant speed. This motion is controlled by a linear actuator or a vertical slide rail to ensure precise positioning at the designated cutting point.
- Cutting process by cylinder saw: when the cassava is in the optimal position, the cylinder saw rotates at a pre-set speed to detach the tubers from the rhizome. The cutting is achieved through the shearing force of the cylindrical saw teeth, resulting in a smooth cut surface and minimizing yield loss.
- Return stroke upon completion of the cut: the gripper mechanism automatically moves back to its initial starting position. This stage ensures continuous operation without the need for a manual reset for every cycle.
- Gripper release stage: once the gripper returns to the starting position, the system releases the clamping pressure and discharges the processed cassava rhizome.

3. Results and discussion

3.1 Physical characteristics

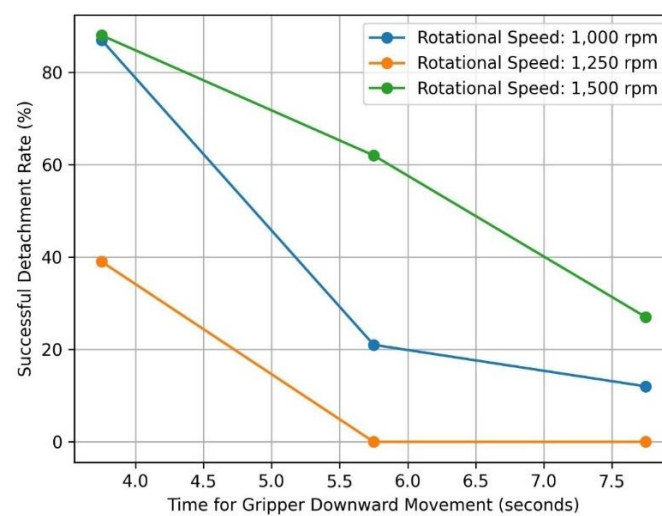
The study of physical characteristics indicates that cassava tubers accumulate nutrients and increase in size relative to their age. Tubers aged 10–12 months were found to be optimal for harvesting. This growth stage was used as the design criterion for the semi-automatic cassava rhizome-tuber cutting machine equipped with a cylinder saw (as shown in Table 2).

Table 2 Physical characteristics of cassava tubers

Physical characteristics studied	Average (6–8 months)	Average (10–12 months)
Cassava plant weight (kg)	3.32	4.35
Stem base diameter (mm)	38.58	45.71
Maximum spread distance (cm)	54.59	31.64
Minimum spread distance (cm)	37.44	44.98
Canopy height (cm)	31.61	30.1

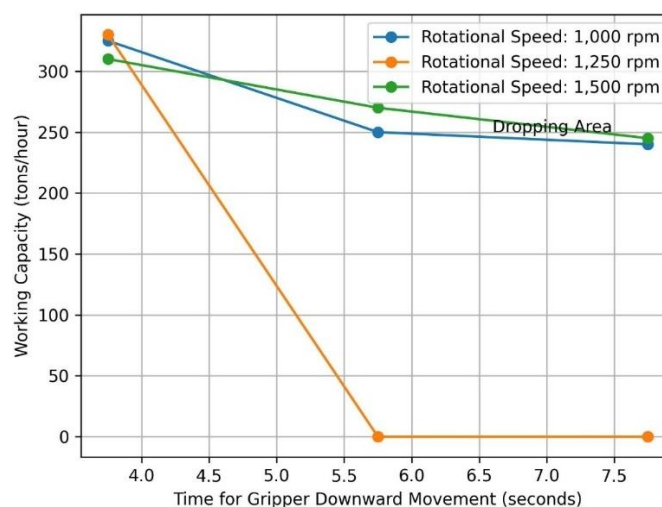
3.2 Cutting efficiency of cassava tuber cutting using the test rig

Based on the experimental results, it was found that as the gripper travel time increased, the working capacity of the test rig tended to decrease. At a cylinder saw speed of 1,250 rpm with gripper downward travel times of 5.75 and 7.75 s, the machine was unable to detach the cassava tubers from the rhizomes. A detailed data inspection revealed that during the test, 3 out of 10 samples failed because the gripper did not reach the bottom dead center (BDC) position (as shown in Figure 2).

**Figure 2** Relationship between gripper downward travel time and the success rate of cassava tuber cutting

3.3 Working capacity of the test rig

Experimental results indicated that lower cylinder saw speeds combined with faster gripper downward travel times tended to yield higher success rates. This was attributed to a consistent shear force and an appropriate compression duration. Specifically, a rotational speed of 1,000 rpm resulted in the highest average working capacity (as shown in Figure 3).

**Figure 3** Relationship between gripper downward travel time and working capacity

3.4 Cassava tuber loss rate

Experimental results showed that a cylinder saw speed of 1,500 rpm with a gripper downward travel time of 5.75 s was the most suitable condition, as it resulted in the lowest loss rate. Regarding the impurity rate analysis, there were no statistically significant differences observed across all test conditions due to the consistently low impurity levels recorded (as shown in Figure 4).

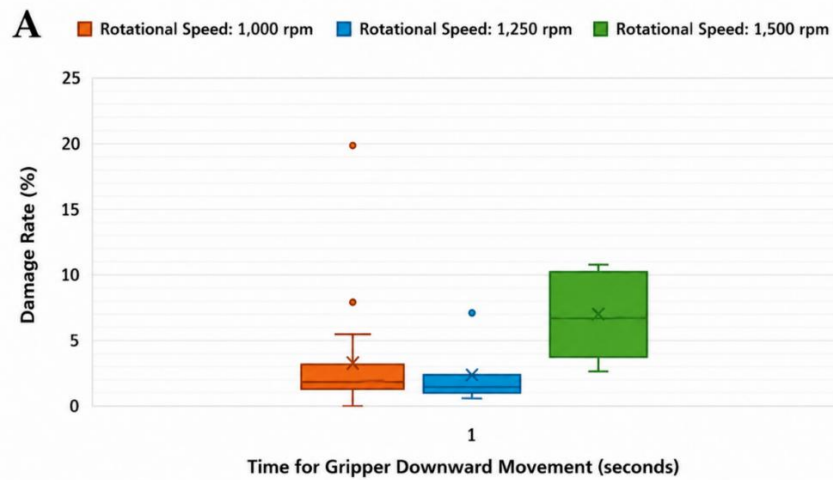


Figure 4 Variance between gripper downward travel time and tuber loss rate

3.4 Electrical energy consumption of the test rig

Based on the experiments, it was found that the cylinder saw speed is a significant factor affecting electrical power consumption. At a rotational speed of 1,000 rpm, the energy consumption was at its lowest and showed a decreasing trend as the gripper downward travel time increased (as shown in Figure 5).

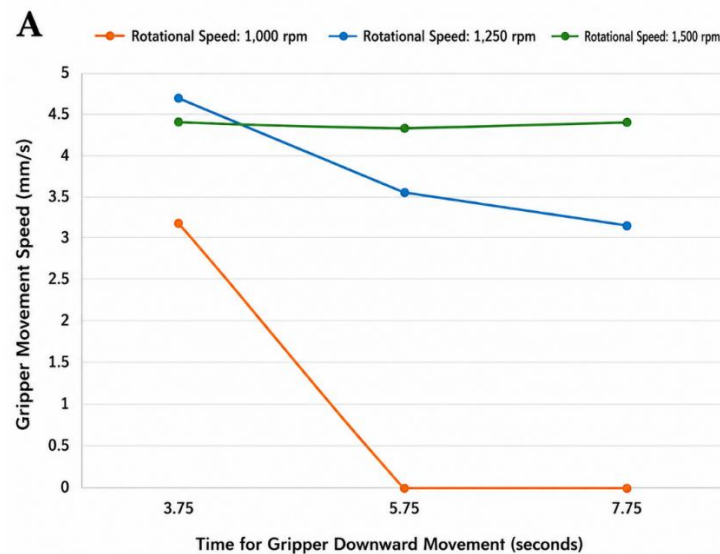


Figure 5 Relationship between gripper downward travel time and electrical energy consumption

3.5 Design criteria for the cassava rhizome-tuber cutting machine

Based on the study of physical characteristics in Table 2 and the performance testing of the test rig, the design criteria for the semi-automatic cassava cutting machine using a cylinder saw can be established. These criteria encompass both physical design requirements and machine performance standards (as shown in Table 3).

3.6 Comparison of working capacity between farmers and the test rig

The comparison of working capacity between manual labor (farmers) and the test rig indicates that the test rig's performance is 1.7–4.7 times higher than that of the farmers. This superiority is attributed to the test rig's ability to maintain a constant cutting speed and eliminate downtime associated with rest periods or ergonomic adjustments required by manual laborers, which are inherent limitations of human performance (as shown in Table 4).

Table 3 Design criteria for the semi-automatic cassava rhizome-tuber cutting machine using a cylinder saw

Key Indicators	Design Criteria
<i>1. Physical Aspects</i>	
1.1 Machine width (Inner frame)	26 – 38 cm
1.2 Clearance between gripper lowest point and saw blade	27 – 33 cm
1.3 Outer gripper jaw dimension	44 – 48 mm
1.4 Inner gripper jaw dimension	30 – 34 mm
<i>2. Performance Aspects</i>	
2.1 Cutting success rate	• Rotational speed: 1,000 and 1,500 rpm • Travel time: 3.75 s
2.2 Working capacity	• Rotational speed: 1,000 and 1,250 rpm • Travel time: 3.75 s
2.3 Cassava tuber loss rate	• Rotational speed: 1,500 rpm • Travel time: 3.75 s
2.4 Electrical energy consumption	• Rotational speed: 1,000 rpm • Travel time: 7.75 s

Table 4 Comparison of working capacity between farmers and the test rig

Operation / Location	Working Capacity (plants/h/person)	Working Capacity (kg/h/person)
Nam Phong plot	190	984.2
Borabue plot	110	111.6
Kut Rang plot	69	303.6
Test rig	323	1,421.20

4. Conclusions

The performance testing results indicate that a cylinder saw speed of 1,000 rpm with a gripper downward travel time of 3.75 s is the most optimal condition for establishing the design criteria of the semi-automatic cassava rhizome-tuber cutting machine. This configuration achieved the highest cutting success rate and working capacity, while maintaining low levels of energy consumption and tuber loss. When compared to manual labor across the studied plots, the test rig demonstrated a working capacity 1.7–4.7 times higher than that of the farmers.

5. Recommendations

Since the test rig was unable to detach cassava tubers from the rhizomes at a cylinder saw speed of 1,250 rpm with downward travel times of 5.75 and 7.75 s, further repetitive testing should be conducted to identify the definitive root causes of this failure. The test rig should be evaluated in actual field operations to compare its practical efficiency when integrated into the cassava harvesting system as a replacement for manual labor.

6. Acknowledgements

We would also like to thank the Department of Agricultural Engineering, Faculty of Engineering, and the Bio-Sensing and Field Robotic Laboratory, Khon Kaen University, for their support in terms of equipment, and tools, which significantly contributed to the smooth and successful completion of this research.

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