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Design and Development of Potato Harvesting Equipment (*solanum tuberosum l.*) for Harvesting Efficiency

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ABSTRACT

Potato (*Solanum tuberosum* L.) is a high-value horticultural crop in Indonesia; however, harvesting is still predominantly conducted manually, resulting in low efficiency, high labor demand, and a high risk of tuber damage. This study aimed to design, develop, and evaluate a semi-mechanical potato harvesting machine suitable for field conditions in Indonesia. The research stages included field observation, computer-aided design (CAD), prototype fabrication, and field performance testing on three planting beds. The parameters evaluated were effective working capacity, harvesting efficiency, and tuber damage percentage. The developed harvester achieved an average effective working capacity of 240.60 Kg/Hour or 0.0118 ha/hour, with a tool efficiency of 65.74%. The average tuber damage was 5.96%, indicating good harvesting quality. These results demonstrate that the developed harvester significantly improves harvesting productivity and reduces yield losses compared to manual methods. Further improvements are recommended, particularly regarding blade-angle adjustment and collection system optimization.

Keywords: potatoes; harvesting equipment; working efficiency; agricultural engineering; agricultural mechanization

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1. Introduction

Indonesia is an agrarian country in which a large proportion of the population depends on agriculture as their primary livelihood. The agricultural sector continues to show strong development potential, supported by abundant natural resources, human capital, and increasing adoption of modern agricultural technologies. Horticulture represents one of the fastest-growing agricultural subsectors,

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encompassing vegetables, fruits, and ornamental plants. Among horticultural commodities, potatoes remain one of the most widely cultivated crops in Indonesia, although national production has fluctuated in recent years. According to the Central Bureau of Statistics [1], potato production reached 1.21 million tons in 2016 with an average productivity of 18.25 tons/ha, decreased to 1.16 million tons in 2017 (15.4 tons/ha), and slightly increased to 1.18 million tons in 2018.

In practice, potato harvesting in Indonesia is still largely performed manually using hoes and simple hand tools. This method requires high labor input, long harvesting time, and large physical effort, while also increasing the risk of mechanical damage to tubers. Several semi-mechanical potato harvesters have been introduced; however, their adoption remains limited due to various technical constraints, such as high draft force, unstable conveying systems, tubers falling through the separator gaps, and inefficient power transmission [2]. These limitations prevent such machines from fully replacing manual harvesting practices.

The development of a field-appropriate semi-mechanical potato harvester equipped with a combustion engine is therefore considered a promising solution to increase working capacity and reduce labor dependency. Several design improvements, such as the use of chain-driven rollers to reduce slip and a V-belt transmission system to stabilize power delivery, are expected to enhance machine performance. However, studies on affordable and adaptable potato harvesters specifically designed for small-scale Indonesian farming conditions are still limited.

Based on this background, this study aimed to design, develop, and evaluate the performance of a potato harvesting machine to improve working capacity, reduce tuber damage, and enhance harvesting efficiency.

2. Materials and Method

This study was conducted in Jorong Simpang Batagak, West Sumatra, Indonesia. The research consisted of two main stages: (1) design and fabrication of the potato harvester prototype and (2) field performance testing.

Equipment and Materials

The fabrication process utilized welding machines, metal benders, grinding machines, hacksaws, and various measuring instruments. The main construction

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materials included forged-steel axles, steel pipes, roller chains, and V-belts. Field tests were conducted using the Cipanas potato variety.

Experimental Procedure

Field performance testing was carried out on three planting beds, each with a width of 1 m. The parameters measured included harvesting time, total harvested potato weight, damaged tuber weight, harvested land area, and operational costs. The effective working capacity based on weight (EWCw) was calculated using:

$$EWC_w = \frac{W}{t}$$

Where W is the harvested potato weight (kg) and t is harvesting time (h). The effective working capacity based on area (EWCa) was calculated using:

$$EWC_a = \frac{A}{t}$$

Where A is the harvested area (ha). The tuber damage percentage (D) was calculated as:

$$D = \frac{W_d}{W} x\ 100\%$$

Where W_d is damaged potato weight (kg).

3. Result

Design Results

The developed potato harvester has dimensions of 150 cm × 50 cm × 90 cm, which align with the Indonesian National Standard (SNI) for potato bed width of 50 cm. During design and field testing, several technical constraints were identified. One issue was the blade tilt angle, which caused the blade to come into direct contact with the ground or road surface when transported, potentially accelerating wear or damage. In the collection section, small potato tubers tended to escape through gaps, indicating that the collection system was not yet fully effective for various tuber sizes. Similar constraints were also reported by Yulfiarno et al. (2023), who noted that excessively wide separator spacing in mechanized harvesters causes small potatoes to fall through and remain uncollected [4]. Additionally, Zakariyya & Hermawan (2024) found that the HD-C1000G potato harvester left behind 6.1% of tubers and

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produced 2.16% mechanically damaged tubers at certain operating speeds, demonstrating the importance of optimizing separator spacing and tool configuration to improve harvesting performance [5].


Figure 1. Potato Harvester Development

Effective Work Capacity

Table 1. Effective Work Capacity

Planting Bed	Total Weight (Kg)	Potato Weight (Kg) — Potato Condition: Broken	Potato Weight (Kg) — Potato Condition: Whole	Time (Hour)	Effective Work Capacity: Weight (Kg/Hour)	Effective Work Capacity: Land Area (Ha/H)
1	20	1	19	0,089	224,72	0,0112
2	22	1	20	0,091	241,76	0,0119
3	24	2	22	0,094	255,32	0,0123
Average	22	1,3	20,3	0,091	240,60	0,0118

The effective working capacity based on potato weight is calculated by dividing the total harvested weight by the harvesting time (kg/hour). The harvester achieved 224.72 kg/hour, 241.76 kg/hour, and 255.32 kg/hour for planting beds 1, 2, and 3, respectively, with an average of 240.60 kg/hour. The average harvest time per bed was approximately 0.09 hours (5.4 minutes), reflecting slight variations in field conditions and equipment performance.

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Area-based effective capacity, calculated by dividing the planting area by harvesting duration (ha/hour), resulted in 0.0112 ha/hour, 0.0119 ha/hour, and 0.0123 ha/hour, with an average of 0.0118 ha/hour. These results align with the revised summary emphasizing the tool's average performance.

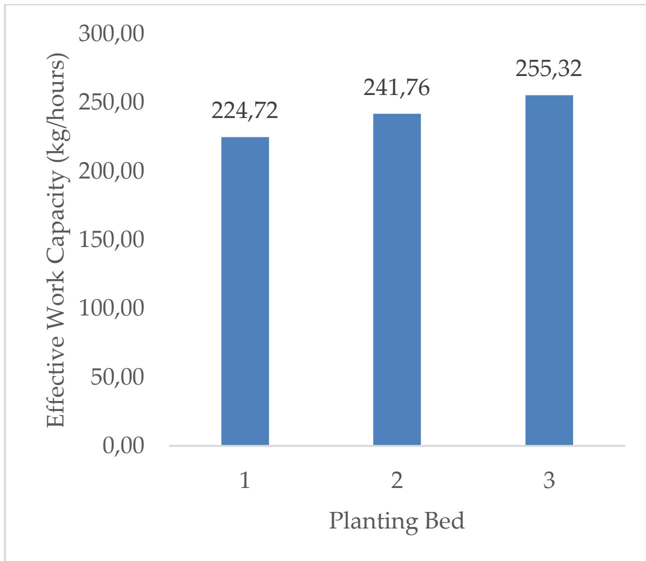

Figure 2. Effective Working Capacity by Weight

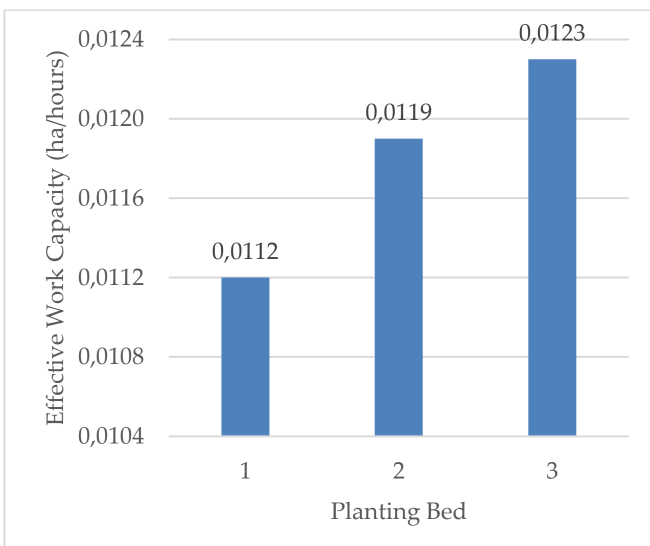

Figure 3. Effective working capacity based on land area

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Percentage of Potato Damage

The percentage of potato damage was determined by dividing the weight of damaged potatoes from each planting bed, then multiplying by 100%. The potato damage percentage table can be seen in Table 2.

Table 2. Percentage of Potato Damage

Planting Bed	Potato Weight (Kg)	Width (m)	Potato Damage (kg)	Percentage of Potato Damage (%)
1	20	1	1	5,00%
2	22	1	1	4,55%
3	24	1	2	8,33%
Average	22	1	1,33	5,96%

Table 2 presents data on potato damage that occurred in three planting beds, focusing on the weight of the harvest, the width of the planting bed, the amount of damage, and the percentage of potato damage. Each planting bed has the same width of 1 meter, making the comparison between planting beds more valid. The weight of potatoes produced varied, with 20 kg in the first planting bed, 22 kg in the second planting bed, and 24 kg in the third planting bed. The potato damage recorded was 1 kg in the first and second planting beds, and 2 kg in the third planting bed.

The percentage of damage was calculated based on the ratio of the number of damaged potatoes to the total weight of harvested potatoes. The results showed that the highest potato damage occurred in the third planting bed with 8.33%, followed by the first planting bed with 5.00%, and the lowest in the second planting bed with 4.55%. Overall, the average potato damage from the three planting beds was 1.33 kg or 5.96%.

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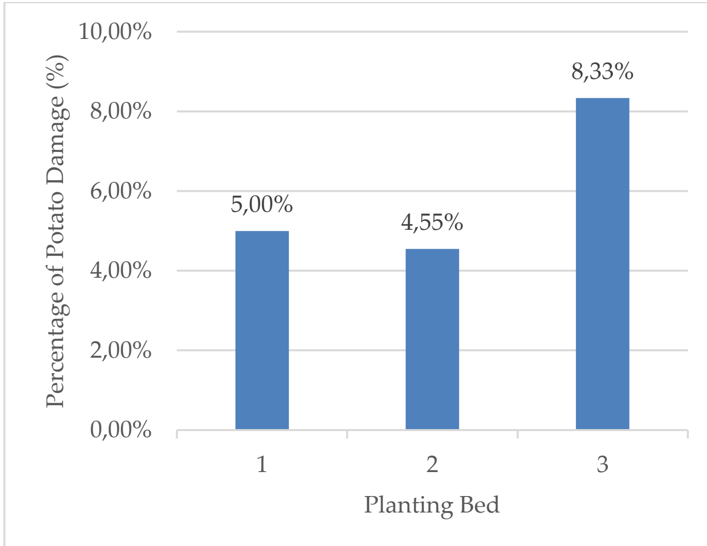

Figure 4. Percentage of Potato Damage

Base Cost

The cost of using potato harvesting equipment consists of fixed and non-fixed costs [6]. The cost calculation based on harvested potato weight (BPa) indicated that planting bed 1 incurred Rp 75.50/kg, planting bed 2 Rp 62.10/kg, and planting bed 3 Rp 51.30/kg. The average cost by weight was IDR 62.97/kg. Meanwhile, based on the harvested land area (BPb), the base cost for planting bed 1 was IDR 1,280/ha, planting bed 2 IDR 1,230/ha, and planting bed 3 IDR 1,160/ha, with an average of IDR 1,223/ha.

Fixed costs include depreciation and capitalized interest from the development of the potato harvester [6]. In this study, annual depreciation costs amounted to Rp 730,000, and capital interest amounted to Rp 145,000 per year, bringing the total fixed costs to Rp 875,000 per year. Non-fixed costs consisted of repair and maintenance expenses of Rp 750/hour and labor costs of Rp 13,000/hour, calculated based on total operation time.

Break-even Point

The break-even point in potato cultivation is an important indicator to determine the minimum production volume or land area that must be achieved so that revenue is equivalent to total production costs, so that the business does not suffer losses. The Break-even Point (BEP) is influenced by fixed costs, variable costs, production costs, and the effective working capacity of the harvesting equipment.

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In this study, the BEP calculation based on the weight of potatoes harvested (BPa) showed that planting bed 1 required 89.50 kg/year, planting bed 2 amounted to 108.20 kg/year, and planting bed 3 reached 132.40 kg/year to break even. Meanwhile, the BEP calculation based on the harvested land area (BPb) shows that planting bed 1 requires 5.200 ha/year, planting bed 2 5.360 ha/year, and planting bed 3 5.710 ha/year. This break-even analysis is in line with the study by Prabowo et al. (2022), which showed that BEP in potato farming can be calculated by considering fixed and variable costs, as well as total revenue [7].

4. Discussion

The results showed that all potato tubers were successfully harvested without any remaining in the soil. This performance was strongly influenced by the inclination angle of the harvesting blade, which exceeded the tuber depth and enabled efficient soil cutting and tuber lifting. During harvesting, two tuber categories were identified: whole tubers—those lifted intact—and damaged tubers, which were cut due to direct contact with the blade. Whole tubers were pushed backward through the roller into the collector, producing weights of 16 kg, 19.5 kg, and 22.5 kg across the three planting beds, with an average of 19.33 kg.

Damaged tubers weighed 1 kg, 0.5 kg, and 0.5 kg per bed, averaging 0.6 kg, equivalent to a 5.96% damage rate. This occurs when the digging depth does not match the tuber position. These findings align with Johnson & Cheein (2023) [8], who reported that improper digging angles and depths significantly contribute to mechanical tuber damage. Increasing the digging angle can improve lifting efficiency but also increases soil resistance, which negatively affects harvesting efficiency and actual field capacity.

The configuration of harvesting equipment—such as digging width, number of rows, and digging depth—also strongly affects harvest quality. Tofeq (2023) found that a two-row digger with a 25-cm digging depth achieved 85.18% whole tubers and 98.22% total yield, with only 3.99% damage [9]. These results reinforce the need to optimize blade geometry and separator spacing to reduce escape of small tubers and minimize mechanical damage.

The Effective Working Capacity (EWC) is influenced by machine speed, soil structure, land slope, operator proficiency, and crop loss—both damaged and

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unharvested tubers [10]. Based on harvested weight, EWC values reached 224.72 kg/hour, 241.76 kg/hour, and 255.32 kg/hour, with an average of 240.60 kg/hour, including both whole and damaged tubers. Area-based EWC reached 0.0112 ha/hour, 0.0119 ha/hour, and 0.0123 ha/hour, consistent with similar prototype or tractor-drawn systems. These results are comparable to the performance of tractor-drawn diggers reported by Bekele et al. (2025) [11], indicating that the developed prototype can notably increase productivity compared to manual harvesting.

Previous studies also emphasize that design factors—such as conveyor configuration, separator spacing, and digging depth—strongly influence both effective capacity and tuber integrity. Wang et al. (2024) demonstrated that integrating conveying and packing systems can significantly enhance harvesting efficiency [12]. Environmental factors such as temperature and humidity may also affect tuber physiological characteristics; for example, Krochmal-Marczak et al. (2020) reported similar effects on sweet potatoes, which may be used as an analog for potato behavior under varying storage conditions [14].

Overall, the results indicate that while the prototype harvester demonstrates promising performance in terms of capacity and harvest completeness, blade geometry, digging depth, and separator spacing still require optimization to further reduce mechanical damage and prevent loss of small tubers.

5. Conclusions

Based on the results of this study, it can be concluded that the use of this potato harvester offers several significant advantages compared to manual harvesting methods. The harvesting process becomes faster, allowing for reduced labor requirements and improved operational efficiency. The tool development test results show that the effective working capacity reaches 240.60 kg/hour, while the theoretical working capacity is 376.57 kg/hour, resulting in a tool efficiency of 65.74%. In addition, the tuber damage percentage is only 5.96%, indicating that the tool performs well in maintaining harvest quality.

However, several improvements can be made to further enhance the tool's performance. First, it is recommended to add a blade-angle adjustment of 30° to regulate the vertical movement of the blade, preventing direct contact with the road surface during transport to the field, which could cause blade wear. Second, the

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potato container should be designed without gaps to ensure that all tuber sizes—especially smaller ones—can be collected properly and do not fall back to the ground after harvesting.

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