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Technical Performance Evaluation of the TEP25 Young Coconut Peeling Machine

Imelda Lumiu[1], Dedie Tooy[2], Ireine A. Longdong[3], David P. Rumambi[4], Daniel P. M. Ludong[5], Herry F. Pinatik[6]
([1,2,3,4,5,6]Agricultural Engineering Study Program, Department of Agricultural Technology, Faculty of Agriculture, Universitas Sam Ratulangi, Indonesia)
Author Corresponding: dtooy@unsrat.ac.id

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Abstract
This study evaluated the technical performance of the TEP25 young coconut peeling machine for micro, small, and medium enterprises (MSMEs) and compared its performance with conventional manual peeling. The evaluation involved six hybrid young coconuts and three respondents, focusing on peeling time, theoretical capacity, operational efficiency, machine rotational speed, product cleanliness, and user perception. The results demonstrated that the TEP25 performed better than the manual peeling method. The machine achieved an average peeling time of 41.67 s fruit^{-1} and a theoretical capacity of 86.39 fruits h^{-1}, whereas manual peeling required 49.60 s fruit^{-1} with a theoretical capacity of 72.58 fruits h^{-1}. Thus, the TEP25 increased peeling capacity by approximately 19% compared with the manual method. The machine achieved an operational efficiency of 91.67%, assuming approximately 5 min of non-productive time during each hour of operation. Its rotational speed decreased from 1479.2 rpm under no-load conditions to approximately 776 rpm under load, indicating the mechanical response of the system during peeling. In terms of product quality, the TEP25 achieved a coconut-water cleanliness score of 5.00/5.00, compared with 3.33/5.00 for manual peeling. Respondents also rated the machine more favorably for comfort, safety, and ease of operation. Overall, the TEP25 demonstrates promising potential to improve peeling productivity, product cleanliness, and workplace safety in MSMEs, although further evaluation using larger sample sizes is recommended.

Keywords: Agricultural Machinery; Coconut Processing; Ergonomics; Peeling Capacity; Postharvest Technology; Young Coconut

Introduction

Indonesia is one of the world's major coconut-producing nations, where coconut-based agriculture and processing form a vital economic backbone for smallholder farmers and micro, small, and medium enterprises (MSMEs) (Saputra & Alamsyah, 2023). Young coconuts are widely sought after as fresh natural beverages and functional foods. Meeting market demand requires an effective postharvest peeling process that delivers high processing rates, visual consistency, food hygiene, and operator safety.

At the retail and small-enterprise level, young coconut peeling remains predominantly manual, relying heavily on traditional machetes or specialized sharp knives (Nawi et al., 2019). While manual peeling requires minimal capital investment and offers high flexibility, its operational throughput is strictly limited by operator skill, fatigue, and concentration. Furthermore, the repetitive high-impact swinging motions introduce severe ergonomic risks—such as musculoskeletal disorders affecting the wrists, shoulders, and lower back—alongside a constant risk of acute lacerations (Gallagher & Heberger, 2013)

To mitigate these drawbacks, several mechanical coconut dehusking and trimming devices have been

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engineered over the past two decades. Early mechanical interventions focused primarily on heavy-duty, fully automated industrial dehuskers (Jide Olusegun Adedipe, 2024) owever, many existing motorized designs are prohibitively expensive, overly complex, energy-intensive, or unsuited for compact retail spaces and small-batch processing. Moreover, existing literature on small-scale peeling machines frequently focuses solely on mechanical throughput or peeling time, leaving critical research gaps regarding power dynamics under load, coconut-water microbial/physical cleanliness, and operator-centric ergonomic safety (Ramaswamy et al., 2022).

This study aims to evaluate the performance of a compact, semi-mechanized young coconut peeling machine (TEP25) tailored for small-scale and retail applications. Specifically, this work investigates power dynamics under operational load, assesses the physical and microbiological cleanliness of the extracted coconut water, and evaluates operator-centric ergonomic safety. It is hypothesized that the TEP25 model significantly reduces peeling time and operator ergonomic strain while maintaining stringent hygienic standards compared to traditional manual methods.

Unlike previous studies, which mainly focused on machine design or peeling capacity, this study provides a more comprehensive engineering evaluation by integrating technical performance, rotational behavior under operational load, operational efficiency, coconut-water cleanliness, and preliminary operator perception into a single assessment framework. This integrated approach provides practical information for developing affordable semi-mechanized peeling technology suitable for MSMEs.

Literature Review

The engineering and development of the semi-mechanized young coconut peeling machine originate from the foundational integration of agricultural material cutting mechanics, mechanical power transmission, and postharvest work capacity efficiency. Grounded in agricultural material cutting theory, the primary theoretical assumption posits that the minimum shear force required to effectively pare and separate the fibrous outer husk (epicarp and mesocarp) is not static, but rather dynamically dictated by the physical properties of the raw material—specifically husk moisture content and fruit maturity—as well as the geometric alignment of the cutting interface, notably the blade orientation relative to the longitudinal direction of the fibers (Rajkumar et al., 2023). Consequently, this theoretical framework provides the mechanistic rationale for optimizing blade geometry, motor power requirements, and continuous rotation stability to lower mechanical energy demands while maintaining cutting quality."

Theoretical Capacity and Operational Efficiency

Theoretical peeling capacity (C, fruits h^{-1}) represents the maximum potential output of the machine without accounting for operational delays. It is mathematically calculated based on the mean single-peeling cycle time (t in seconds):

$$C = \frac{3600}{\mathrm{t}}$$

However, in field operations, overall equipment effectiveness (OEE) is constrained by non-productive downtime, such as fruit loading and unloading, husk debris clearance, and operator fatigue. Operational efficiency (E, %) is calculated by comparing the effective productive time (Te) to the total operational time (Tt):

$$A = \frac{Te}{Tt} \times 100\ \%$$

Rotational Dynamics and Power Transmission

When an electric motor encounters mechanical load from the frictional forces between the cutting blade

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and the coconut husk, a rotational speed drop (slip) occurs. The magnitude of the RPM drop from no-load to loaded conditions reflects the adequacy of motor torque and the transmission efficiency of the pulley and V-belt system (Jarimopas & Thanapase, 2007). An excessive reduction in rotational speed can impair cutting efficiency and increase the risk of blade wear or stalling.

Preliminary Evaluation Boundaries and Sample Validity

In early-stage agricultural machinery engineering research, proof-of-concept testing frequently employs limited sample sizes to verify baseline mechanical functionality prior to large-scale performance trials **(**Ramaswamy et al., 2022)**.** Although testing with a sample size of n = 3 per treatment does not meet the requirements for inferential statistical hypothesis testing, this descriptive approach provides critical baseline performance indicators to identify initial design limitations and repeated trials under different operating conditions to improve statistical power and external validity.

Research Method

Study site and materials

The study was conducted from December 2025 to January 2026 at the Agricultural Engineering Workshop, Faculty of Agriculture, Universitas Sam Ratulangi, Manado, Indonesia. Six hybrid young coconuts with relatively uniform maturity were selected for the direct peeling test. The recorded fruit mass was approximately 2–3.4 kg. The principal equipment consisted of the TEP25 young coconut peeling machine powered by a 0.5-hp electric motor, a machete or sharp knife for manual peeling, a stopwatch, tachometer, digital balance, collection containers, coconut perforating tools, and a vernier caliper.

TEP25 machine and operating principle

The TEP25 is a semi-mechanized peeling machine comprising a rigid angle-steel frame, an electric motor, a pulley and V-belt transmission system, a rotating lower fruit holder, an upper spring-assisted retaining mechanism, and manually actuated cutting tools. During operation, the coconut is clamped vertically and rotated by the driven shaft. A side blade is progressively applied to remove the outer husk, while an upper blade is used to shape the top portion of the fruit.

Figure 1. TEP25 young coconut peeling machine.

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Experimental procedure

Before testing, the TEP25 was cleaned and inspected to ensure normal operation. Coconuts were selected to minimize variation in maturity and size. Because this study represents an initial prototype evaluation, a limited number of relatively homogeneous coconuts were used to establish baseline engineering performance before conducting larger-scale validation experiments. Three coconuts were peeled individually using the TEP25, and three were peeled manually by an experienced young-coconut vendor. Peeling time for each fruit was measured with a stopwatch. Machine rotational speed was measured using a tachometer under no-load and loaded conditions. Fruit mass before and after peeling was recorded during machine tests. Additionally, non-productive downtime including fruit loading/unloading, husk clearance, blade adjustments, and operator rest intervals was continuously recorded to measure actual operational field efficiency.

Performance indicators

Theoretical Peeling Capacity (C, fruits h-1) was calculated as $C = 3600 / t$, where t is the mean peeling time in seconds, while Operational Efficiency (E %) was evaluated using two distinct metrics: Theoretical Operational Efficiency, estimated as $E = (T_e / T_t) \times 100\%$ assuming 55 min of productive time per 60-min period (5 min non-productive downtime), and Actual Operational Efficiency, calculated using $E = (T_e / T_t) \times 100\%$, where T_e is the measured productive peeling time and T_t is the total elapsed operational time logged during continuous field trials.

Product cleanliness and user assessment

Coconut-water cleanliness after peeling was evaluated visually using a five-point ordinal scale: 1 = poor clarity with abundant husk particles; 2 = turbid; 3 = moderately clear with a small amount of debris; 4 = clear with almost no visible debris; and 5 = very clear with no visible husk particles. Three respondents evaluated comfort, perceived safety, and ease of operation using a five-point rating scale. The questionnaire results are presented descriptively because of the limited number of respondents.

Data analysis

Data collected during the technical evaluation—including peeling time, theoretical capacity, motor rotational speed, coconut-water cleanliness scores, and user perception ratings—were initially summarized using descriptive statistics (mean, standard deviation, and percentage differences), followed by exploratory inferential analysis to evaluate whether observed differences between the TEP25 machine and manual peeling reached statistical significance despite the small sample size ($n = 3$ per group). Continuous variables (peeling time in seconds and theoretical capacity in fruits h^{-1}) were analyzed using Welch's t-test and the non-parametric Mann-Whitney U test to account for small-sample variance and potential non-normality, while ordinal data from the 5-point cleanliness scale and user perception ratings (comfort, safety, and ease of operation) were evaluated using the Mann-Whitney U test at a significance threshold of alpha = 0.05. Executed as exploratory testing, these inferential procedures provide formal p-values while explicitly acknowledging that the high risk of Type II errors due to limited statistical power ($n = 3$) require non-significant findings to be interpreted with caution until validated through larger replicated trials.

Therefore, the statistical analyses presented in this study should be interpreted as exploratory and descriptive rather than confirmatory because of the limited sample size.

Results and Discussion

Machine rotational behavior

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The motor-driven system operated at 1479.2 rpm under no-load conditions and dropped to a mean loaded rotational speed of 775.9 pm 2.36 rpm (773.8, 775.4, and 778.5 rpm), representing a substantial speed reduction of 47.5% during coconut paring. This sharp velocity decay directly reflects agricultural cutting mechanics, where the tangential and radial shear resistance of the fibrous *epicarp* and *mesocarp* imposes heavy peak loads that force the 0.5 hp motor down its speed-torque curve (Ghani et al., 2018; Pranav et al., 2012). Furthermore, V-belt drive compliance inherently experiences mechanical slip and elastic creep across pulleys under high torque, a phenomenon similarly observed in small-scale postharvest machinery (Jarimopas & Thanapase, 2007; Ramaswamy et al., 2022). Because such severe speed fluctuations compromise cutting stability, peeling uniformity, and motor thermal efficiency, future design iterations must incorporate torque logging, power consumption analysis, and a higher-torque transmission or flywheel to maintain rotational stability throughout the complete peeling cycle.

Figure 2. Initial configuration of the TEP25 machine.

Table 1. 3 Trials and the Speed (rpm)

Trial	No-load speed (rpm)	Loaded speed (rpm)
1	1479.2	773.8
2	1479.2	775.4
3	1479.2	778.5
Mean	1479.2	775.9

Peeling time and theoretical capacity

The TEP25 achieved a lower mean peeling time than the manual method. The average machine peeling time was 41.67 s fruit^{-1} compared with 49.60 s fruit^{-1} for manual peeling. Based on these mean values, theoretical capacities were 86.39 and 72.58 fruits h^{-1}, respectively. The resulting capacity improvement was approximately 19%. These findings suggest that the TEP25 can increase throughput while reducing direct dependence on repetitive machete cutting (Table 2). Nevertheless, the individual observations varied substantially, and the machine was not faster in every trial. This variability, together with the small sample size, demonstrates the need for a larger paired experiment using coconuts stratified by mass, diameter, maturity, and husk thickness.

Table 2. Comparison of Manual Peeling and with The TEP25

Trial	Manual peeling (s fruit^{-1})	TEP25 (s fruit^{-1})
1	76.8	60.0
2	49.0	39.0
3	23.0	26.0
Mean	49.60	41.67
Method	**Mean peeling time (s fruit^{-1})**	**Theoretical capacity (fruits**

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		h^{-1})
Manual	49.60	72.58
TEP25	41.67	86.39

Estimated operational efficiency

Assuming 5 min of non-productive time during a 60-min operating period, the estimated operational efficiency of the TEP25 was 91.67%. This value indicates a high proportion of productive time under the stated assumption. However, a stronger engineering assessment should determine non-productive time directly during extended operation and should include fruit loading and unloading, cleaning, blade adjustment, interruptions, and minor maintenance. The present value should therefore not be interpreted as a fully validated field efficiency.

Cleanliness of coconut water

The visual cleanliness score was consistently higher for coconuts processed using the TEP25. The machine-treated samples received a mean score of 5.00, indicating no visible husk contamination, whereas manually processed samples received a mean score of 3.33. The more controlled cutting path of the TEP25 may reduce the introduction of husk fragments during preparation. However, the present assessment was based on a subjective visual scale. Future studies should use blinded assessors and, where possible, objective measurements such as filtration residue, turbidity, or particle counts.

Table 3. Manual score and Tep25 score for user perception

Sample	Manual score	TEP25 score
S1	3	5
S2	4	5
S3	3	5
Mean	3.33	5.00

User perception and ergonomic implications

Three respondents rated the TEP25 more favorably than manual peeling for comfort, perceived safety, and ease of use (Table 3). The reported mean TEP25 scores were 4.00 for comfort, 5.00 for safety, and 4.33 for ease of operation. The fixed cutting mechanism and rotating fruit holder may reduce direct exposure to a hand-held blade and may decrease repetitive upper-limb effort. Nevertheless, these results represent user perceptions rather than a formal ergonomic assessment. Claims concerning reductions in musculoskeletal load should be validated using established methods such as RULA or REBA, task-cycle observation, posture analysis, and a substantially larger respondent sample.

Technical significance and study limitations

The main practical value of the TEP25 lies in integrating fruit rotation, controlled blade application, and top shaping within a compact semi-mechanized platform designed for small-scale vendors. Mechanistically, the observed 19% increase in throughput and higher cleanliness ratings stem from fundamental biomechanical and kinetic advantages over manual peeling: the motorized rotational chuck converts the labor-intensive, multi-directional cutting motion into continuous, uniform tangential surface speed relative to the stationary blade, significantly reducing tool-workpiece impact dissipation and operator fatigue. Furthermore, replacing open-blade swinging with enclosed, mechanically guided tool feeding restricts husk debris propagation, preserving coconut-water hygiene by preventing epicarp/mesocarp particulate contamination during perforation. However, several methodological limitations constrain broad generalization: only six fruits were tested, treatment assignments lacked full statistical replication, operational efficiency relied on assumed downtime, and ergonomic/cleanliness scores were derived from small subjective panels. To advance this preliminary proof-of-concept into a

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publishable confirmatory study, future research must utilize 10–30 fruits per method in a randomized block design with a standardized peeling endpoint. Scientifically rigorous testing should quantify kinetic energy consumption, specific energy requirement (kJ.kg-1), percentage mass removed, blade edge degradation kinetics, operational noise and vibration spectrums, and objective quantitative food safety parameters.

Conclusion

In this preliminary evaluation, the TEP25 young coconut peeling machine demonstrated a potential peeling time of 41.67 s fruit^{-1}, a theoretical capacity of 86.39 fruits h^{-1}, and an estimated operational efficiency of 91.67%, representing an estimated capacity gain of ~19% over manual peeling. Regarding product quality, the TEP25 achieved higher visual coconut-water clarity without husk contamination (cleanliness score of 5.00/5.00) and reduced the risk of water loss. Furthermore, operators reported favorable initial perceptions regarding comfort (4.00), safety (5.00), and ease of operation (4.33). However, these findings remain preliminary baseline indicators, and definitive claims regarding long-term productivity and ergonomic safety require confirmation through larger replicated trials. Accordingly, the present results should be regarded as preliminary engineering evidence supporting further prototype development rather than definitive confirmation of machine performance.

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