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Design of a Machine to Separate Pepper from Stalks for Small-Scale Farmers

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Abstract

Small-scale pepper farmers, particularly in Tuai Rumah Mawas, face persistent challenges in efficiently detaching pepper from their stalks, especially during peak harvesting seasons. Current manual methods are highly labour intensive, time consuming, and unsustainable for long term agricultural productivity. Furthermore, traditional wooden sorting tools deteriorate quickly due to constant exposure to moisture and seasonal flooding, further exacerbating post-harvest inefficiencies. This study aims to design a semi-automated pepper stalk separation machine that addresses the post-harvest constraints faced by smallholder farmers, with the specific objective of increasing processing capacity and reducing dependency on manual labour. The machine is designed to operate on a standard 230V power supply with a motor speed of 1400 rpm, capable of processing up to 50 kg of pepper within 30 minutes. The design incorporates corrosion-resistant materials for enhanced durability and ergonomic features to ensure safe and user-friendly operation. Preliminary performance assessments indicate that the machine can reduce labour costs by up to 85% and achieve a processing throughput of approximately 1.67 kg/min, thereby significantly improving productivity and sustainability for rural pepper farming communities.

Keywords: - Pepper processing, small-scale farmers, agricultural machinery, sustainability, ergonomic design, stalk separation

1. Introduction

Pepper (Piper nigrum L.) remains a cornerstone of Malaysia's spice industry, with Sarawak recognized as the nation's primary production hub, supplying over 95% of the country's total output (The Borneo Post, 2023). For rural and indigenous communities, pepper farming not only represents a key source of income but also carries deep cultural and socio-economic significance. However, the post-harvest phase, particularly the separation of pepper from stalks, continues to rely heavily on traditional manual methods. This labourious task poses significant challenges for smallholder farmers, especially during peak harvesting periods when workforce availability is limited.

The persistence of manual stalk removal methods leads to reduced efficiency, inconsistent product quality, and heightened physical strain on an aging agricultural workforce. In a study by Mazlan et al. (2020), these challenges were further compounded by limited mechanization options and insufficient access to modern agricultural technologies tailored for small-scale operations. Although state-level initiatives have started promoting technological innovations to improve pepper production, the availability of simple, cost-effective post-harvest machinery remains inadequate (The Borneo Post, 2023).

To address this critical gap, this study aims to design and develop a machine specifically tailored for smallholder farmers, which facilitates the separation of pepper from its stalks. The proposed solution incorporates an electric motor-driven rotary separation system, operating at 1400 rpm with a 230V power source, capable of processing up to 50 kg of pepper within 30 minutes. Prioritizing resilience in Sarawak's humid and flood-prone conditions, the machine utilizes corrosion-resistant materials and a lightweight yet durable structural design. Ultimately, this innovation aims to streamline post-harvest processing, reduce dependency on manual labour, and contribute to the long-term sustainability of smallholder pepper farming.

2. Literature Review

The Malaysian pepper industry is largely sustained by smallholder farmers operating plots of less than 0.1 hectares (Mazlan et al., 2020). These small-scale cultivators encounter persistent operational barriers, particularly labour scarcity, limited access to mechanization tailored for smallholders, and the demographic challenge of an aging workforce.

Despite ongoing technological initiatives, there remains a critical gap in accessible, affordable post-harvest machinery specifically designed for small-scale pepper farmers. Manual removal of pepper stalks, though traditional, is inefficient and physically demanding, often leading to inconsistent product quality and reduced processing capacity during peak harvest periods.

Mechanization has been widely acknowledged for enhancing efficiency and reducing human fatigue in spice processing. Studies such as Balli et al. (2020) demonstrated the successful implementation of a semi-automated de-stalking machine for bird's eye chili, achieving significant reductions in manual labour while improving throughput. Similarly, Khandetod (2019) reviewed the impact of mechanization on spice crop processing, highlighting benefits such as improved product consistency, reduced processing time, and overall operational effectiveness.

Despite its advantages, mechanization adoption among small-scale farmers remains low due to barriers such as high equipment costs, limited technical know-how, and lack of localized machine designs (Ministry of Agriculture and Food Industries Malaysia, 2020). Furthermore, Malaysia's tropical climate, characterized by high humidity and frequent flooding, demands machinery that is robust, rust-resistant, and easy to maintain criteria often overlooked in generic agricultural equipment.

Recent initiatives in Sarawak have focused on integrating digital technologies such as IoT and AI for crop monitoring and yield optimization (The Borneo Post, 2023). However, these high-tech solutions may not immediately benefit smallholders lacking infrastructure and resources. Therefore, the development of practical and affordable mechanized solutions is essential to overcome post-harvest bottlenecks, especially for the process of separating pepper from its stalks.

3. Methodology

3.1 Problem Identification and Needs Analysis

The initial stage of this study involved a comprehensive review of relevant literature to identify the persistent post-harvest challenges encountered by smallholder pepper farmers in Sarawak. Previous studies (Mazlan et al., 2020 & Entebang et al., 2020) consistently highlight the labour-intensive nature of manually removing pepper stalks, which requires significant physical effort and limits processing capacity, especially during peak harvest seasons. The continued dependence on traditional methods, such as using wooden sticks and manual hand picking, contributes to low productivity, inconsistent product quality, and increased post-harvest losses.

In addition to the literature review, informal consultations were conducted with local farmers in Tuai Rumah Mawas area to validate the relevance of these issues in the current context. Feedback from stakeholders confirmed that the manual removal of stalks remains a significant bottleneck, exacerbated by labour shortages and an aging farming population

This study employed a dual approach by combining an extensive literature review with direct stakeholder engagement to comprehensively understand the challenges faced by smallholder pepper farmers. Informal consultations with local farmers in the Tuai Rumah Mawas area were conducted to validate the relevance of these issues in the current context. Findings from both literature and field feedback consistently highlighted that the manual process of separating pepper from its stalks remains a significant bottleneck. This challenge is further exacerbated by labour shortages and an aging agricultural workforce, leading to reduced productivity and increased post-harvest losses.

The integration of these insights enabled the formulation of clear functional requirements for the development of a semi-automated machine designed to assist in the separation of pepper from its stalks.

Key design considerations include improving processing efficiency, reducing physical labour demands, ensuring affordability for small-scale farmers, and selecting materials suitable for flood-prone agricultural environments. A summary of the challenges identified through this study is presented in Table 1, while a graphical distribution of these issues is illustrated in Fig. 1.

Table 1: Challenges encountered in the traditional process of removing pepper stalks

Challenges	Percentage of Respondents (%)
High physical fatigue	65%
Time-consuming process	72%
High labour cost	58%
Low productivity/output	60%
Inconsistent quality due to manual work	42%
Lack of suitable machinery	75%

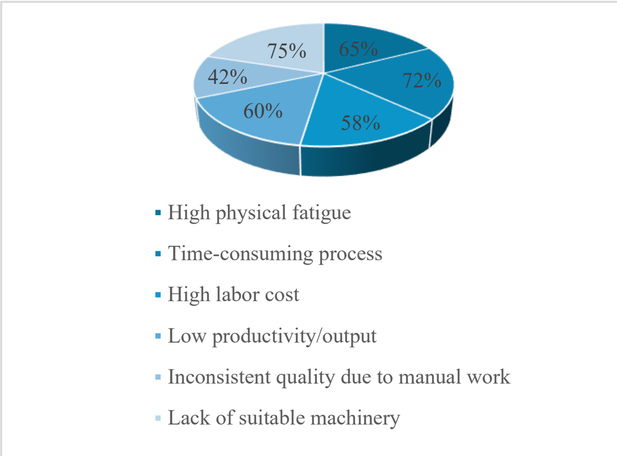

Fig. 1: Distribution of respondents (%) based on identified challenges in traditional pepper stalk removal

3.2 Conceptual Design and Material Selection

Based on the identified requirements, several conceptual designs were generated using morphological charts. This involved evaluating multiple combinations of power sources, transmission mechanisms, separation techniques, structural materials, and output collection methods. The objective was to develop a configuration that balances performance, durability, cost, and ease of use. Table 2 presents the morphological chart of all design alternatives considered.

Table 2: Morphological chart

Function	Option 1	Option 2	Option 3
Power source	Electric motor (230V)	Battery-powered DC motor	Manual crank
Transmission	Belt drive	Chain drive	Gear drive
Separation Mechanism	'Gusar' (Rotating shaft)	Vibrating sieve	Brushing cylinder
Frame Material	Aluminium	Mild steel	Stainless steel
Output Collection	Tray and chute	Conveyor belt	Rotating bin

Subsequently, a Pugh Matrix analysis was employed to systematically evaluate and select the most feasible design concept. The Pugh Matrix facilitated objective comparisons against predefined Product Design Specification (PDS) criteria, considering factors such as performance, cost, manufacturability, and environmental suitability. (Matousek, 2012).

Three alternative design concepts; Concept A, Concept B, and Concept C were evaluated, as illustrated in Fig. 3(b), to (d), respectively. The traditional manual method was used as the baseline reference (datum), as shown in Figure 3a. The comparison utilized a Pugh Matrix systematically assesses performance across key design criteria, such as cost, efficiency, durability, safety, and environmental resistance. As shown in Table 3, Concept A (Motorized, Belt Drive) achieved the highest score, demonstrating superiority in operational reliability, user-friendliness, and suitability for rural deployment.

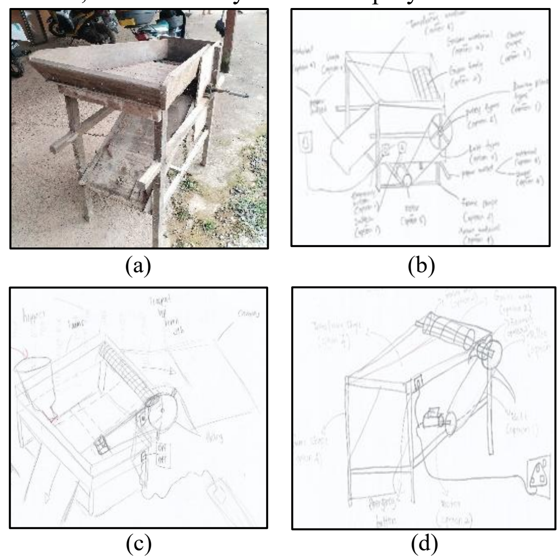

Fig. 3: (a) Traditional design, used as a datum, (b) concept A (Motorized, Belt Drive), (c) concept B (Motorized, Chain Drive), (d) concept C (Motorized, Gear Drive)

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3.3 Detailed Design and Component Selection

The selected concept underwent detailed design development using Autodesk Inventor software to create accurate models and technical drawings. The core components of the machine include the electric motor, pulley system, frame structure, and the 'gusar' rotary shaft designed to perform the stalk removal mechanism. Each part was selected based on criteria such as durability, ease of maintenance, corrosion resistance, and suitability for humid and flood-prone conditions prevalent in Sarawak and similar regions.

Table 3: Pugh Matrix for concept selection

Criteria	Concept A	Concept B	Concept C	Datum
Cost	-1	-1	-1	
Efficiency	+1	+1	+1	
Ease of Use	+1	0	0	
Maintenance	0	0	0	
Durability	+1	0	+1	
Safety	+1	-1	-1	
Environmental Resistance	+1	+1	+1	
Lightweight	-1	-1	-1	
Total Score	**+5**	**+2**	**+3**	

*+1 = better than datum; 0 = same as datum; −1 = worse than datum

For the structural frame, aluminium alloy and treated hardwood were selected due to their favorable strength-to-weight ratio, corrosion resistance, and availability. These materials offer a balance between mechanical integrity and long-term resistance to environmental degradation. The choice aligns with findings from Balli et al. (2020), who emphasized the importance of material selection in enhancing the longevity of agricultural equipment under harsh conditions.

The power transmission system employs a V-belt mechanism that transfers rotational motion from a 230V, 1,400 rpm electric motor to the gusar shaft. This method was selected for its simplicity, low cost, and reliability. The pulley configuration was optimized to ensure consistent torque delivery and to minimize slippage, while a protective guard was included to improve operator safety during operation (Fig. 4)

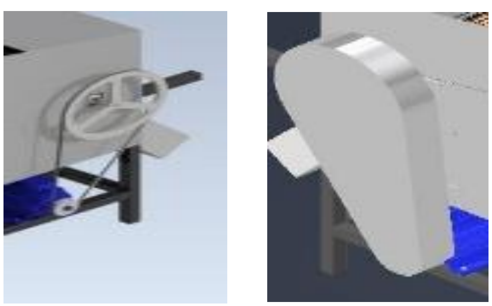
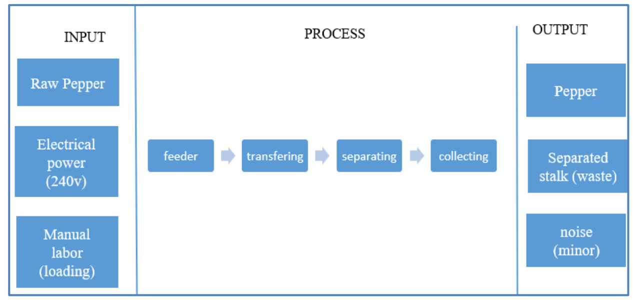


Fig. 4: V-Belt Pulley System for power transmission from electric motor to gusar shaft

To support a clear understanding of the machine's operation, a Black Box Diagram (see Fig. 5(a)) was developed to represent the system's inputs, processes, and outputs. Additionally, a transparent diagram (see Fig. 5(b)) illustrates the internal component arrangement and the sequential flow from pepper loading to stalk separation and output collection.

(a)



(b)

Fig. 5: (a) Black box diagram of machine (b) Transparent system diagram showing operational flow

The finalized configuration ensures compatibility with semi-rural conditions, particularly in areas with limited access to advanced tools or maintenance facilities. The system was designed to be user-friendly, modular, and robust attributes critical for sustainable implementation in smallholder farms.

3.4 Risk Analysis and Evaluation

A Design Failure Mode and Effects Analysis (DFMEA) was systematically conducted to identify potential failure modes and implement preventive measures for the machine (Fakhravar, 2020).

The analysis specifically focused on critical components that directly influence the machine's operational reliability and user safety, namely the electric motor, 'gusar' mechanism, belt drive system, and structural frame. By anticipating possible points of failure, the DFMEA aimed to enhance the machine's durability and ensure consistent performance under typical smallholder farming conditions (Zadry et al., 2018).

Key risk areas identified include overheating of the electric motor, mechanical jamming in the gusar unit due to inconsistent pepper sizes, belt slippage, and frame instability under prolonged stress. These issues, if left unaddressed, could result in equipment downtime, safety hazards, or increased maintenance costs. Table 4 summarizes the main findings from the DFMEA process.

The mitigation strategies proposed include the use of thermal protection systems for the motor, design adjustments in the gusar shaft to accommodate various pepper sizes, and implementation of fastening techniques to resist vibrational loosening. Additionally, the adoption of sealed bearings, protective casing for wiring, and scheduled maintenance protocols is recommended to prolong equipment life and ensure user safety.

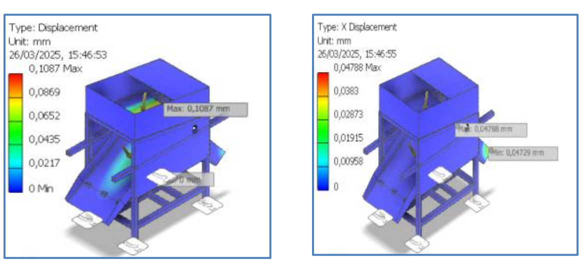
Table 4: Summary of Design Failure Mode and Effects Analysis (DFMEA)

Component	Potential Failure Mode	Effect	Cause	Prevention / Control Measure
Electric Motor	Overheating	Shutdown, or internal damage	Prolonged use, poor ventilation	Install thermal overload protection; improve airflow system
'Gusar' Mechanism	Jamming	Halts operation; stress buildup	Varying pepper sizes, clogging	Design adjustable clearances; enable easy disassembly for cleaning.
Bolt and Nut Joints	Loosening of fasteners	Structural vibration, instability	Continuous vibration, improper torque	Use locking washers or thread-lock compounds; apply torque standards.
Belt Drive System	Slippage	Reduced efficiency, timing loss	Incorrect belt tension	Integrate tension adjuster; regular belt checks
Electrical Wiring	Short circuit	Fire hazard, malfunction	Moisture ingress, loose terminals	Ensure cable insulation and sealing; use protective conduits.
Machine Frame	Deformation	Reduced alignment, poor output	Mechanical shock, overload	Reinforce frame; select high-strength materials with appropriate safety factor
Bearings	Seizure/Wear	Noise, friction, operational loss	Dust contamination, lack of lubrication	Use sealed bearings; enforce routine lubrication

By incorporating these preventive measures during the design phase, the machine's robustness is significantly improved, thereby increasing its suitability for real-world agricultural conditions. The proactive use of DFMEA thus contributes not only to technical reliability but also to the overall sustainability of the solution for rural farming communities.

To assess the structural integrity and operational performance of the proposed pepper stalk removal machine, a Finite Element Analysis (FEA) was conducted using Autodesk Inventor simulation tools. The analysis focused on evaluating deformation, displacement, and vibrational responses under typical operational loads.

Fig. 6(a) shown the simulation results indicated a maximum displacement of 0.1087 mm, demonstrating that the machine's frame experiences minimal deformation under expected load conditions. The displacement was well-distributed, with most of the structure exhibiting negligible deflection, confirming that the frame is rigid and robust. These findings suggest that the design is structurally sound and capable of withstanding applied loads without significant distortion or risk of failure.



(a) (b)

Fig. 6: Finite element analysis (FEA) (a) structural load analysis (b) lateral displacement analysis

Further analysis of X-axis displacement revealed a maximum lateral shift of 0.04788 mm as shown in Fig. 6(b). This minimal side-to-side movement indicates that the structure maintains excellent lateral stability under operational stresses. The minor deformation observed was localized in non-critical areas, while the remaining structure showed stable and uniform load distribution. These results validate the reliability of the design, ensuring consistent performance during extended use.

3.5 Ergonomic and Sustainability Considerations

In addition to mechanical and structural performance, the final machine design incorporates ergonomic and sustainability features to enhance user experience and support long-term adoption in rural settings. These considerations are particularly relevant for smallholder farmers who face labour constraints and limited access to maintenance services.

From an ergonomic perspective, the machine was designed to minimise physical strain and accommodate a wide range of user profiles. Key ergonomic features include:

i. Adjustable working heights to suit various operator statures;
ii. Strategically positioned control switches for ease of use;
iii. Designated safe zones for loading and unloading materials.

These elements collectively reduce operator fatigue and support prolonged use, addressing the needs of an ageing farming population in regions such as Sarawak, where ease of use significantly influences technology adoption.

Furthermore, the user interface was simplified to enable intuitive operation, requiring minimal training for first-time users. Standing posture operation helps mitigate repetitive motion injuries typically associated with manual stalk removal. Protective guards were also integrated to shield users from moving parts, enhancing overall operational safety

From a sustainability consideration, it was prioritised through careful material and component selection, focusing on environmental resilience and energy efficiency. The use of corrosion-resistant aluminium and treated hardwood extends the machine's lifespan in humid, flood-prone environments, thereby reducing waste and replacement frequency.

Energy efficiency was addressed by incorporating an electric motor with a consumption rate of approximately

0.37 kWh per operating cycle, making the machine suitable for areas with limited electrical infrastructure.

Maintenance-friendly design features include sealed bearings, a belt-driven transmission system, and modular construction. These elements simplify servicing, reduce maintenance frequency, and lower the total cost of ownership, especially important in rural areas with limited access to specialised repair services. According to Mazlan et al. (2020) the machine's design emphasized simplicity, ease of maintenance, and energy conservation, ensuring long-term viability and encouraging adoption among smallholder farmers.

The integration of ergonomic and sustainability enhancements ensures the machine's practicality, user comfort, and long-term operational viability. These design considerations support broader adoption among smallholder farmers and contribute to the development of more resilient and sustainable agricultural practices.

4. Result and Discussion

This section presents the outcomes of the conceptual design development for a semi-automated machine intended to separate pepper from their stalks. The discussion highlights the performance estimates, ergonomic features, cost analysis, and broader implications for smallholder farming operations.

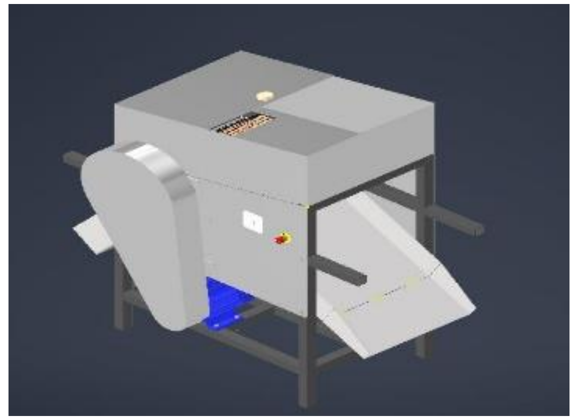
Evaluation of the design was conducted based on established criteria including processing capacity, material durability, operational safety, and economic feasibility within rural agricultural settings.

4.1 Final Design Description

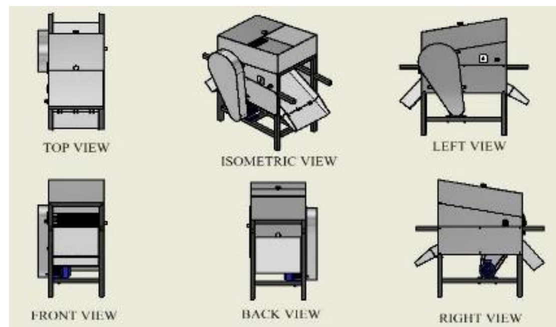
The final design, derived from Concept A, which utilizes a motorized belt-drive system. This configuration was selected due to its favourable performance in key criteria such as efficiency, maintenance, and environmental resistance. The finalized system operates using a 230V electric motor running at 1400 rpm, which powers a rotating gusar shaft through a V-belt transmission. The mechanism is optimized for efficient separation of pepper from their stalks while maintaining ease of use.

Fig. 7(a) and (b) illustrate the final design model, including orthographic and isometric views, for visual reference and component identification. Key features of the final design include:

i. A belt drive system offering reliable and low maintenance power transmission.
ii. A structural frame constructed from aluminium and treated hardwood for corrosion resistance and environmental durability.
iii. A compact, ergonomic layout aimed at reducing operator fatigue through optimized working height and user-friendly control placement.
iv. Protective housings and safety guards around moving parts to ensure operator safety during operation.



(a)



(b)

Fig. 7: (a) Final design of machine (Modified concept A) and (b) Orthographic and isometric views

These key features help to minimize risk during machine operation and ensure compliance with basic safety standards in smallholder environments.

4.3 Discussion of Design Advantages

An economic feasibility assessment was conducted, estimating the prototype production cost at RM 1,800, which encompasses material expenses, motor and transmission components, as well as assembly labour. With an expected lifespan of five years and assuming seasonal usage, the projected cost per operation cycle remains competitively low. This supports the machine's affordability and suitability for smallholder farmers.

Based on field interviews and average wages (RM6/hour), traditional manual separation of 50 kg of pepper typically requires 5 – 6 labour per hours (approx. RM30 – RM36 per batch). In contrast, the proposed machine can perform the same task in 30 minutes with minimal supervision, reducing direct labour costs by up to 85%. Assuming 2 cycles per day during the harvest season over 60 days, projected labour cost savings could reach RM3000 – RM4000 annually, justifying the RM1800 investment within two seasons.

A cost-benefit comparison with the traditional manual stalk removal process revealed a projected break-even point within 1.5 years of operation. This economic advantage is attributed to the following:

i. Significant reduction in labour hours required for stalk removal.

ii. Substantial increase in processing speed and throughput.
iii. Minimized physical fatigue experienced by workers.

Collectively, these benefits contribute to enhanced productivity while reducing dependence on manual labour, which is often scarce in smallholder farming communities. Therefore, the adoption of this mechanized solution is strongly justified, particularly in low-resource agricultural environments where efficiency, labour optimization, and cost-effectiveness are critical for sustaining farm operations.

From a design improvement perspective, the incorporation of treated hardwood and aluminium addresses common durability concerns, such as decay and corrosion, which are prevalent in humid and flood-prone regions like Sarawak and Sabah. These materials were selected to ensure long-term resilience and reduce maintenance needs in challenging environmental conditions.

Ergonomic considerations were also prioritized, with features such as easily accessible control switches, optimized working height to reduce operator fatigue and user-friendly interface for simplified operation. These enhancements aim to improve operational comfort and reduce physical strain, making the machine more accessible and practical for aging farmers and limited labour forces. Such ergonomic upgrades are particularly crucial for ageing farmer populations and reduce the likelihood of repetitive strain injuries.

A Design Failure Mode and Effects Analysis (DFMEA) was performed during the early design stages to proactively identify and address potential failure risks. Key concerns such as motor overheating and inefficient stalk removal mechanisms were analyzed and mitigated through design refinements, ensuring reliable and consistent machine performance.

The design approach aligns with findings by Balli et al. (2020), who emphasized the importance of durable materials and ergonomic layouts in improving the usability and acceptance of agricultural machinery among smallholder farmers. This reinforces the relevance and practicality of the proposed solution in addressing the specific needs of the target user group.

The machine's estimated processing capacity was calculated based on the design specifications and mechanical simulations. The key performance indicators are as follows:

a) Processing throughput

Approximately 1.67 kg/min, enabling the processing of 50 kg of pepper in under 30 minutes.

b) Energy consumption

Estimated at 0.37 kWh per cycle, supporting the machine's feasibility for use in areas with limited electrical infrastructure.

Additionally, Finite Element Analysis (FEA) was performed to assess the structural integrity of critical components, confirming that the design meets acceptable stress and deformation limits under operational loads.

This validation ensures safe and reliable operation within the targeted agricultural environments. Table 5 shows a summary of comparison of proposed machine vs traditional manual method.

Table 5: Comparison of proposed machine vs traditional manual method

Criteria	Traditional Manual Method	Proposed Pepper Stalk Removal Machine
Labour Intensity	High physical effort	Minimal physical effort (semi-automated)
Processing Speed	Low (~10–15 kg/hour)	High (~100 kg/hour)
Productivity	Labour-dependent	Scalable and consistent
Product Quality	Inconsistent due to manual variability	Uniform and controllable
Operational Cost	Low upfront, high recurring labour cost	Moderate upfront, low long-term cost
Ergonomics	Causes operator fatigue	Ergonomically optimized
Material Durability	Prone to wear and moisture damage	Corrosion- and flood-resistant
Maintenance & Reliability	Requires frequent replacement	Low-maintenance, robust
Rural Suitability	Manual, no power required	Low energy consumption (0.37 kWh/cycle)
Sustainability	Not scalable	Supports sustainable practices

4.4 Implications for Smallholder Farmers

The design of pepper stalk separation machine presents significant implications for smallholder farmers, particularly those operating in resource-constrained environments. By reducing dependency on labour and increasing post-harvest processing speed, the machine can directly enhance productivity, reduce physical strain, and improve overall farm income.

In regions where agricultural labour is declining and ageing, automation solutions such as this are critical. The machine's ease of operation, affordability, and low maintenance requirements make it suitable for immediate implementation in smallholder settings without the need for intensive training or infrastructure upgrades.

The design also aligns with broader rural development and sustainability goals by introducing a scalable and energy-efficient technology that preserves product quality, reduces waste, and enables greater consistency in production. These features are crucial during peak harvesting periods when efficiency is vital to minimize losses

These implications are supported by prior findings (Mazlan et al., 2020), which emphasize the transformative role of context-appropriate mechanization in improving smallholder resilience, efficiency, and market competitiveness. The proposed machine represents a practical and economically viable step toward that goal.

5. Conclusion and Recommendations

This study successfully developed a conceptual design for a machine intended to separate pepper from their stalks, aiming to enhance post-harvest handling efficiency for smallholder farmers in Sarawak. Through a systematic design approach that integrated stakeholder input, literature review, and engineering analysis, the machine was tailored to meet the operational, ergonomic, and environmental needs of rural farming communities.

The final design incorporates a belt-driven rotary separation mechanism powered by a 230V, 1,400 rpm electric motor, capable of processing 50 kilograms of pepper in under 30 minutes. Materials such as treated hardwood and aluminium were selected to ensure corrosion resistance, structural durability, and suitability for humid, flood-prone agricultural environments. The machine also emphasizes ergonomic considerations, including adjustable working height and safe operator interfaces, to reduce fatigue and promote user comfort.

Finite Element Analysis (FEA) confirmed that the machine exhibits minimal structural deformation under operational loads, indicating strong mechanical integrity. Additionally, the estimated energy consumption of 0.37 kWh per cycle and an affordable projected production cost of RM 1,800 further supports the design's feasibility and cost-effectiveness for smallholder adoption.

While the design outcomes are promising, the current limitation lies in the absence of a fabricated prototype. All performance evaluations are based on simulations and theoretical assumptions. Therefore, further validation through prototyping and field testing is necessary to confirm the machine's effectiveness under real-world agricultural conditions.

5.1 Recommendations

To facilitate the successful deployment and future scaling of the proposed machine, the following recommendations are put forward:

a) Prototype fabrication and field testing

A fully functional prototype should be fabricated and subjected to comprehensive field trials in actual farming environments. These trials should evaluate the machine's processing throughput, energy consumption, ease of use, and reliability under various crop conditions and moisture levels. Such testing will provide critical data for iterative design refinement and confirm real-world applicability.

b) Design optimization and cost reduction

Insights from field testing should guide targeted design improvements, particularly in refining the separation mechanism to enhance efficiency while minimizing damage to pepper. To improve affordability, locally available materials and simplified manufacturing processes should be explored. Modular design approaches should also be considered to support easy maintenance and scalability.

c) Market feasibility and sustainability assessment

A market feasibility study should be conducted to assess demand potential, distribution logistics, and scalability, especially in key pepper-producing regions like Sarawak and Sabah. Additionally, collaborations with agricultural agencies and cooperatives may facilitate subsidy programs or financing schemes for smallholder farmers. An environmental impact assessment should also be undertaken to ensure alignment with sustainable agricultural practices and circular economy principles.

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Conflicts of Interest: The authors declare no conflict of interest.

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