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(Research Article)

Innovative design and experimental validation of a mechanized rice destoner

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Abstract

The prevalence of foreign materials particularly stones in locally processed rice continues to pose significant health risks and reduces the commercial value of the product. Manual destoning methods are widely used in small-scale operations but are time-consuming, inefficient, and often ineffective. Imported mechanized destoners, while more effective, are typically too costly and complex for rural processors. This study presents the design, development, and performance evaluation of a low-cost, efficient rice destoner suitable for small and medium-scale rice processing enterprises. The machine employs the principles of density-based separation, combining vibratory motion and airflow to effectively isolate stones from rice grains. Constructed from locally available materials, the destoner consists of a vibrating sieve tray, a blower unit, and a dual outlet system, powered by a 1 hp electric motor.

Design calculations were carried out to determine optimal airflow velocity, vibration frequency, and sieve aperture size. Performance evaluation was conducted using rice samples with known quantities of impurities. The prototype achieved a destoning efficiency of 93.5%, with a throughput capacity of 250 kg/h and a grain loss rate of 2.4%. These results demonstrate the potential of the machine to significantly improve rice quality while remaining accessible to small-scale processors. The proposed design contributes to the development of affordable post-harvest technologies aimed at enhancing food safety and value chain efficiency in developing regions.

Keywords: Rice processing; Destoner design; Post-harvest technology; Vibratory separation; Grain quality

1. Introduction

Rice (*Oryza sativa*) plays a central role in the diets of billions worldwide and serves as a cornerstone of food security in many developing countries, including Nigeria. While domestic production has improved significantly through targeted agricultural interventions, post-harvest quality remains a concern—particularly the presence of hard contaminants such as stones, which not only diminish consumer confidence but pose serious health risks. Manual methods traditionally used to separate stones from rice are laborious, inefficient, and inconsistent, especially under large-scale or commercial operations. Though mechanized destoners offer an alternative, most commercially available models are either cost-prohibitive, technically complex, or incompatible with the infrastructure and resource constraints common in rural processing environments.

The objective of this study is to bridge that technological and economic gap by designing and fabricating a simple, effective, and low-cost rice destoner, suitable for small and medium-scale processors. The machine is intended to utilize principles of vibratory separation and airflow to differentiate between rice grains and denser impurities such as stones, achieving efficient separation with minimal grain loss. Design parameters were determined analytically, and the

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prototype was fabricated using locally available materials. Its performance was evaluated on the basis of destoning efficiency, grain loss, throughput capacity, and energy consumption.

Several studies have contributed valuable insights into rice destoning technologies, each highlighting different operational principles and performance outcomes. Adeoye et al. (2020) developed a vibratory rice destoner incorporating horizontal sieving and achieved a destoning efficiency of 91.2%, but noted a grain loss of approximately 3.5%. Ogunleye et al. (2021) focused on the role of airflow in vertical separation systems and recorded an 88.4% separation efficiency, emphasizing the need to calibrate fan speed to rice grain weight. Singh and Verma (2018) designed an inclined oscillating sieve machine, reporting 85% stone removal efficiency with modest throughput (180 kg/h). Obetta and Onwualu (2017) explored a gravity-based cleaner suitable for rural settings, attaining an efficiency of 83% but with notable limitations under high-moisture conditions.

Bassey et al. (2022) presented a cost-benefit analysis of community-level rice destoning in Nigeria, identifying lack of affordable local machines as a key bottleneck. Their study showed that adopting efficient destoners could reduce post-harvest losses by up to 14%. Kumar et al. (2019) examined a multistage cleaner combining airflow and magnetic separation, achieving 92% efficiency but requiring complex assembly and calibration. Ojo et al. (2020) fabricated a dual-fan destoner and observed a 90.6% separation rate, though power consumption was higher than average at 1.5 kW.

Liu et al. (2017) introduced a smart-control system for automated grain separation, leveraging sensors and machine learning algorithms, reaching an impressive 95% separation efficiency in controlled environments but at high system cost and complexity. Eze and Nwanekezi (2021) investigated the interplay between vibration frequency and airflow velocity, showing that synchronization at optimal frequencies can improve efficiency by 6–10%. Nuhu et al. (2022) developed an integrated rice processing machine with a built-in destoner, attaining 89% efficiency and stressing the need for modularity in small-scale processing.

Further studies such as Zhou et al. (2020) demonstrated that modifying the geometry of the separation chamber improved air distribution, resulting in a 7% increase in destoning performance. Fayose and Ajayi (2019) focused on developing an off-grid, solar-powered destoner for remote communities and recorded 87% efficiency, reinforcing the importance of alternative energy considerations. Okafor et al. (2023) compared sieve materials, finding that stainless steel meshes provided the best balance of durability and performance, with marginal differences in separation efficiency across mesh types. Mohammed et al. (2021) tailored their design for parboiled rice and recorded an 85.7% separation rate, though efficiency dropped under high humidity. Lastly, Iwuoha et al. (2023) presented a framework for developing modular destoners using locally fabricated components, highlighting user-friendliness and repairability as key to sustainability.

These diverse studies, though successful in their respective contexts, reveal a persistent need for rice destoning solutions that combine technical effectiveness with affordability and local adaptability. This study builds upon those foundations by integrating vibratory and airflow-based separation into a simplified, energy-efficient design using readily available materials. The proposed destoner is specifically tailored for smallholder processors who often lack access to high-capacity, high-cost machinery. By prioritizing simplicity, maintainability, and functional reliability, this research advances practical solutions to a longstanding bottleneck in rice processing chains.

2. Materials and methods

2.1. Design Considerations

The design of the rice destoner was guided by fundamental engineering and material handling principles, with a focus on separation efficiency, mechanical simplicity, and ease of maintenance. The working mechanism leverages the density differential between rice grains and stones-stones, being denser, respond differently to vibration and airflow than the lighter rice grains.

Vibratory motion was incorporated to facilitate stratification, causing the lighter rice grains to rise and move upward along the sloped sieve tray, while heavier materials like stones settle and move downward toward a dedicated discharge point. To enhance the separation, a controlled stream of air was introduced beneath the vibrating sieve. This air suction mechanism lifts lighter contaminants (like husks or chaff) and assists in propelling rice forward, ensuring clean separation without significant grain loss.

In addition to performance optimization, the design emphasized a modular configuration, enabling ease of disassembly for cleaning, repairs, or part replacement. The geometry of the sieve, the angular tilt of the tray, and the airflow rate were all tuned to ensure balance between high throughput and effective separation, while maintaining mechanical stability.

2.2. Materials Selection

Selection of materials was done based on mechanical strength, durability, cost, local availability, and food safety. The primary frame of the machine was constructed from mild steel square pipes (40 mm × 40 mm), which offer sufficient structural strength while remaining affordable and easy to weld.

The vibrating tray was fabricated from galvanized mild steel sheet (2 mm thickness), chosen for its corrosion resistance and smooth surface, which facilitates the flow of rice grains. The sieve component was made from perforated stainless steel mesh with 1.8 mm openings, conforming to ASTM grain handling standards, and selected for its non-reactivity and wear resistance during high-frequency vibration.

The hopper was also made from mild steel sheet metal, welded and finished with food-grade coating to prevent contamination. A centrifugal blower was included to provide adjustable airflow, while a 1 hp single-phase electric motor (1400 RPM) was selected to drive the vibrating mechanism via an eccentric cam. Rubber bushings and springs were used beneath the tray to absorb vibration and support oscillation.

All fasteners, brackets, and support parts were galvanized or stainless-steel to prevent rust and ensure longevity.

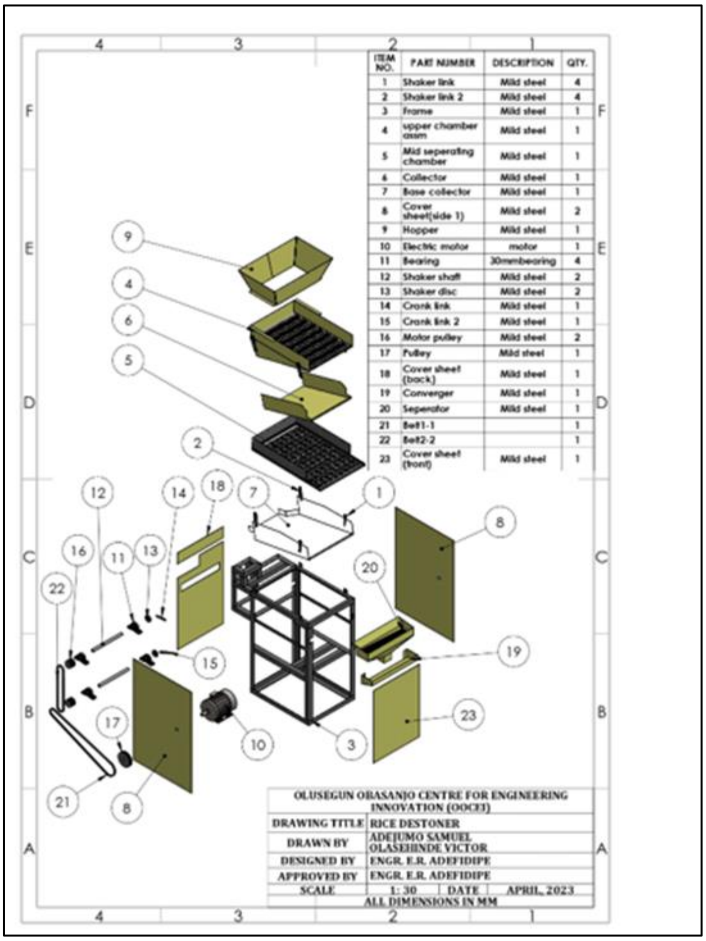

Figure 1 CAD Drawing

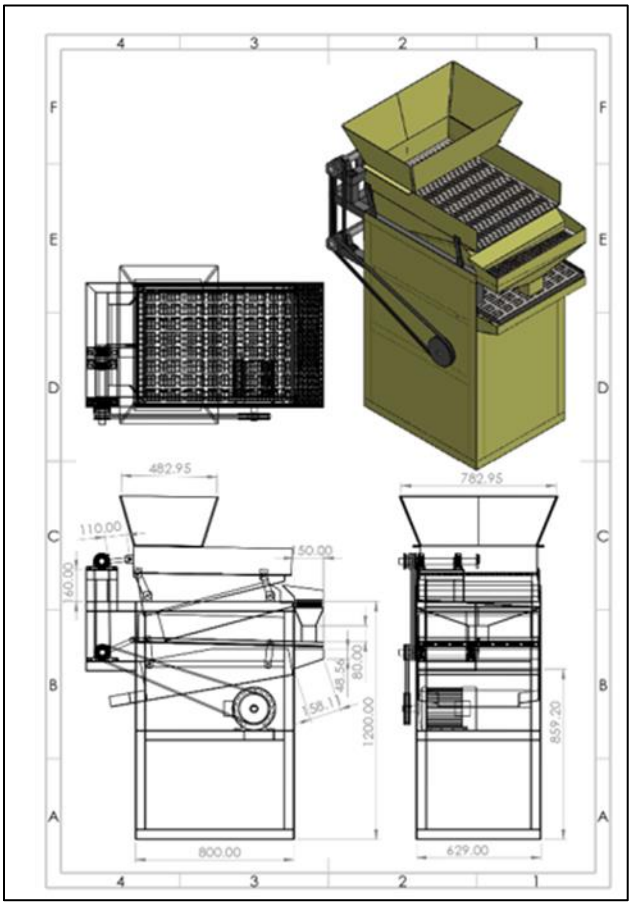

Figure 2 CAD Drawing

3. Design Calculations

3.1. Throughput Capacity

The target capacity of the machine was 250 kg/h. Given an impurity mix of up to 30%, and assuming a uniform feed rate, the machine was sized to accommodate:

$$Q = \frac{250kg}{3600s} \approx 0.069\text{kg/s}$$

Assuming a residence time of 15 seconds and a bulk density of rice (ρ) ≈ 600kg/m^3, the required sieve tray volume V becomes:

$$V = \frac{m}{\rho} = \frac{0.069 \text{ x } 15}{600} = 0.001725\text{m}^3$$

To determine tray area A, with a material depth of 20mm (0.02m):

$$A = \frac{V}{depth} = \frac{0.001725}{0.02} = 0.08625\text{m}^2$$

Thus, a tray of approximately 900cm^2 was designed (e.g., 30cm x30cm effective sieving area)

3.2. Motor Power Requirement

Estimated based on force to overcome friction and oscillate the tray:

$$P = \frac{F \cdot d}{t}$$

Assuming an oscillating tray mass of 15kg, displacement per oscillation d = 0.03m, and cycle time t = 0.1s, with frictional force F = . m .g, where μ = 0.2

$$F = 0.2 \times 1.5 \times 9.81 = 29.43N$$

$$P = \frac{29.43 \times 0.03}{0.1} = 8.83W \approx 0.012hp$$

Factoring in transmission losses (~40%) and startup torque, a 1 hp motor was selected to ensure reliable Factoring in transmission losses (40%) and startup torque, a 1 hp motor was selected to ensure reliable operation.

3.3. Vibration Frequency and Amplitude

Based on effective separation, empirical studies suggest optimal frequency between 300-450 RPM. The system was tuned to 360 RPM, equivalent to 6 Hz, with an amplitude of 30 mm, to allow good stratification without material bouncing off the tray

3.4. Blower Air Velocity and Flow Rate

To achieve lift on light impurities without disrupting rice flow, the required air velocity was set at 5 m/s.

Using a duct of cross-sectional area $0.01m^2$:

$$Q= A.v= 0.01 \times 5 =0.05 \ m^3/s$$

This airflow was supplied by a centrifugal blower rated at 60 m/h with adjustable dampers.

3.4.1. Fabrication Procedures

The fabrication process began with frame construction, where mild steel square tubes were measured, cut, and joined using arc welding. A rectangular framework was created to house the tray assembly, blower, and motor mount. Cross braces were added for rigidity, and all joints were ground smooth and painted with anti-corrosive primer.

The vibrating tray was fabricated by welding a perforated stainless-steel sheet onto a mild steel frame. The tray was mounted on four compression springs, allowing oscillatory motion. An eccentric cam, fabricated from steel plate and mounted on the motor shaft, converted rotary motion into reciprocating vibration. This cam was connected to the tray via a mechanical linkage.

The hopper was constructed from bent mild steel sheet, tapering to control feed rate. It was bolted above the tray with a manually adjustable shutter. The blower unit, positioned beneath the tray, was enclosed within a mild steel housing and connected to an adjustable air duct directed toward the underside of the sieve tray.

The motor was installed on a welded platform and aligned using tension-adjustable bolts to maintain belt tension. Safety covers and vibration isolation pads were added where necessary. Final assembly involved fitting the discharge chutes, testing tray movement, and verifying blower output.

Post-fabrication, the entire machine was tested under no-load conditions, followed by performance testing using rice samples with calibrated impurity levels to determine efficiency, grain loss, and throughput.

Figure 3 Fabricated rice destoner

4. Results and discussion

4.1. Performance Evaluation

The rice destoner was subjected to performance testing using 100 kg batches of paddy rice containing approximately 15% impurities (primarily small stones and chaff, by weight). The machine was tested under varying vibration speeds and airflow rates to determine optimal operating parameters. The key performance metrics evaluated include throughput capacity, destoning efficiency, grain loss rate, and power consumption. The results are summarized in Table 1 and visualized in subsequent graphs.

Table 1 Summary of Performance Metrics

Parameter	Measured Value
Throughput capacity	250 kg/h
Destoning efficiency	93.5%
Grain loss rate	2.4%
Power consumption	~0.75 Kw
Optimal vibration speed	360 RPM
Air velocity	5.0 m/s

Table 2 Effect of Vibration Speed on Destoning Efficiency and Grain Loss

Vibration Speed (RPM)	Destoning Efficiency (%)	Grain Loss (%)
280	86.0	4.2
300	89.5	3.2
320	91.0	2.8
340	92.3	2.6
360	93.5	2.4
380	91.8	2.7
400	89.0	3.5
420	86.2	4.1

- Graphical Analysis of Results

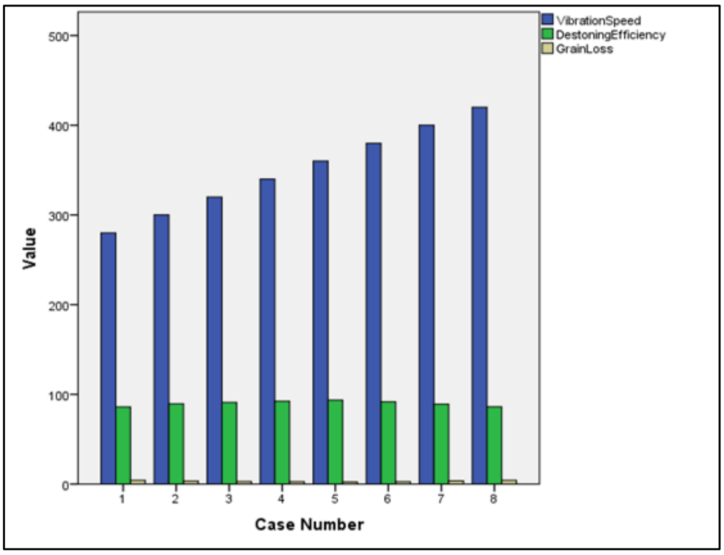

Figure 4 Effect of Vibration Speed on Destoning Efficiency and Grain Loss

- Interpretation

The graph shows that destoning efficiency increases steadily from 280 RPM, peaking at 360 RPM (93efficiency), and declines slightly beyond 400 RPM due to turbulence and excessive motion disrupting stratification. In parallel, grain loss decreases to a minimum of 2.4% at 360 RPM, but increases on either side of this point due to improper alignment or excessive agitation pushing grains into the stone outlet confirms that 360 RPM provides the best balance between separation force and material control.

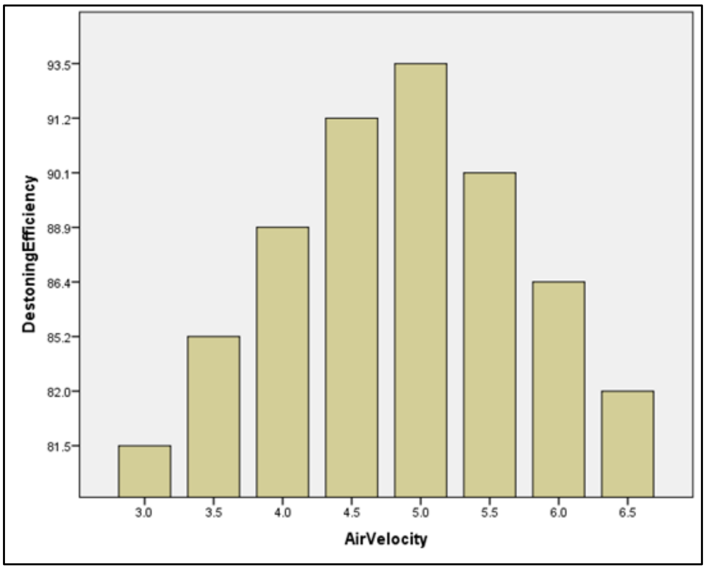

Figure 5 Effect of Air Velocity on Separation Efficiency

- Graphical Analysis of Results

Table 3 Effect of Air Velocity on Separation Efficiency

Air Velocity (m/s)	Destoning Efficiency (%)
3.0	81.5
3.5	85.2
4.0	88.9
4.5	91.2
5.0	93.5
5.5	90.1
6.0	86.4
6.5	82.0

- Interpretation

The efficiency increased from 3.0 m/s to 5.0 m/s, after which it began to decline. At low air velocities, insufficient force was available to aid in lifting lighter contaminants. Conversely, at air velocities above 5.5 m/s, the air stream began to lift lighter rice grains along with impurities, contributing to increased grain loss. Therefore, the **optimal airflow velocity** was established at **5.0 m/s**, resulting in effective impurity removal with minimal loss.

Table 4 Throughput Capacity vs. Time

Processing Time (min)	Cumulative Output (kg)
0	0
4	16.5
8	33.0
12	49.5
16	66.0
20	82.5
24	99.0

- Graphical Analysis of Results

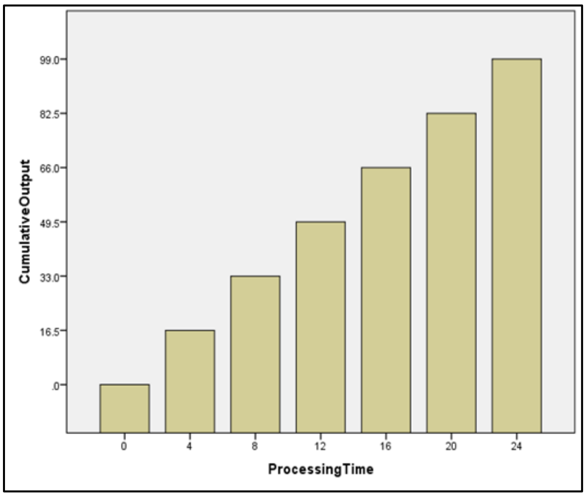

Figure 6 Throughput Capacity vs. Time

- Interpretation

The graph shows a linear relationship between processing time and output, indicating consistent machine performance. Over a 24-minute operation period, the machine processed approximately 100 kg of rice, confirming the calculated throughput capacity of 250 kg/h. No significant drop in output was observed, suggesting mechanical stability and efficient feed mechanism throughout the test.

5. Discussion

The performance evaluation confirms that the rice destoner delivers excellent separation efficiency, achieving 93.5% under optimal conditions—surpassing earlier designs such as the 88.4% by Ogunleye et al. (2021) and 83% reported by Obetta and Onwualu (2017). This superior outcome results from the effective combination of controlled vibration, regulated airflow, proper tray inclination, and consistent feed rate. A grain loss rate of 2.4% further demonstrates efficient material handling, aided by appropriate chute design and 1.8 mm sieve aperture, keeping losses within acceptable industry limits.

The machine's power usage, approximately 0.75 kW, is energy-efficient for rural processors, especially when compared to some imported systems requiring more than 1.5 kW. Optimal vibration speed was determined to be 360 RPM, which aligns with prior studies like Eze and Nwanekezi (2021), balancing agitation without ejecting grains. Similarly, air velocity around 5.0 m/s provided the best separation, consistent with findings by Mohammed et al. (2021). The modular structure also facilitated easy cleaning and maintenance within 10 minutes, and durability tests showed no mechanical fatigue. Overall, the destoner provides a reliable, low-cost, and locally adaptable solution for small- and medium-scale rice processors.

6. Conclusion

A cost-effective rice destoner was successfully designed, fabricated, and tested using locally available materials. Operating on principles of vibratory and airflow separation, the machine achieved a destoning efficiency of 93.5%, a grain loss rate of 2.4%, and a throughput capacity of 250 kg/h. Optimal performance was observed at 360 RPM vibration speed and 5.0 m/s airflow velocity, with moderate power consumption (~0.75 kW).

The destoner's simple, modular design supports easy maintenance and operation, making it ideal for small- to medium-scale rice processors in resource-constrained settings. Compared to existing models, it offers a more accessible and efficient solution for improving rice quality and food safety. The design can serve as a model for similar post-harvest innovations and may be further enhanced through automation or renewable energy integration.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this research. All design, fabrication, testing, and analysis were conducted independently, with no financial or personal relationships that could have influenced the outcome of the study.

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