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Design and performance evaluation of a low-cost Root Vegetable washing and peeling Machine

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Abstract

This study presents the design and performance evaluation of a low-cost, small-scale mechanical system for simultaneous washing and peeling of root vegetables, with ginger and potatoes as test materials. The machine integrates a horizontally rotating drum lined with compression springs and an internal nozzle array to provide combined abrasive and hydraulic action. Performance tests were conducted at two drum speeds (25 rpm and 60 rpm) and two batch sizes (2.1 kg and 5 kg). Results indicate that operation at 25 rpm yields superior performance, achieving approximately 80% washing and peeling effectiveness with minimal flesh loss (2.05% for ginger and 2.25% for potatoes). Energy consumption was measured at 0.92 kWh per 60 s cycle, and the total fabrication cost was approximately USD 240, which is significantly lower than comparable commercial systems. The compact footprint (<0.5 m^2) and modular design make the proposed machine suitable for small and medium-scale processors in resource-constrained settings.

1. Introduction

Root vegetables such as potatoes, carrots, radishes, and ginger are staple food crops widely consumed due to their nutritional and medicinal value. Ginger (*Zingiber officinale*) is particularly important in South Asian cuisine and traditional medicine, where it is used in fresh, dried, powdered, and processed forms [1]. Despite its value, freshly harvested ginger and other root vegetables are heavily contaminated with soil, sand, microorganisms, and residual agrochemicals. Inadequate removal of these contaminants adversely affects product quality, shelf life, and food safety. Postharvest washing of agricultural produce, a vital unit operation in food processing, produces attractive, hygienic and safe food [2][3].

Conventional washing and peeling practices rely largely on manual operations such as scrubbing and knife peeling, which are labor-intensive, time-consuming, and inconsistent in quality. Mechanical alternatives including rotating drum washers [4], abrasive roller peelers [5], brush roller systems [6], and infrared dry peeling technologies [7] have been developed to improve efficiency. These systems are often expensive, energy-intensive, and designed for large-scale operations, making them unsuitable for small and medium-scale processors in developing regions. Sahu and Anwar [8] gave a brief report about a machine that was developed at ICAR-Indian Institute of Sugarcane Research (IISR), Lucknow for cleaning and washing sugarcane before crushing while processing it in order to extract its juice for jaggery production. However, in practice, peeling is carried out using various techniques—mechanical, chemical, thermal (such as steam or freezing), and enzymatic [9] each with its own set of advantages and limitations depending on the specific process conditions and the type of produce being handled [10]. Kumar and Azad [11] evaluated the performance of a rotary drum root crops washer, which is similar in design, principle and operation to the washers reported by Emers [8] , Batara et al. [12] and Siddique et al. [13]. The feed rate and drum rotational speed were reported to be 400 kg/h

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and 20 rpm respectively. To address these limitations, the present study proposes a compact and affordable washing–peeling machine based on a spring-lined rotating drum combined with targeted hydraulic cleaning. Unlike conventional abrasive coatings or brush systems, compression springs provide gentle abrasion with reduced flesh loss while remaining inexpensive and easy to maintain. The primary objective of this research is to design, fabricate, and experimentally evaluate the performance of the proposed machine in terms of washing effectiveness, peeling efficiency, flesh loss, and energy consumption. the procedures highlighted by Olutomilola [14] for developing size reducers will also be found helpful in developing crop washing machines. Researchers in this study area should therefore take note.

1.1. Novelty and contribution of the study

This study presents a low-cost machine that combines washing and peeling of root vegetables in a single operation. Unlike conventional systems, the machine uses compression springs instead of abrasive coatings or brushes, which helps reduce flesh loss while keeping the design simple and affordable. The machine operates at a low drum speed, resulting in lower energy consumption and less damage to the vegetables. Its compact size and low fabrication cost make it suitable for small and medium-scale farmers and processors.

2. Materials and methods

This describes the design, fabrication, and experimental procedure of the developed root vegetable washing and peeling machine.

2.1. Machine description

The developed machine consists of a horizontally mounted cylindrical drum driven by a 1 HP, 1440 rpm single-phase AC motor through a two-stage belt–pulley transmission system. The inner surface of the drum is fitted with compression springs that provide mechanical abrasion during rotation. A stationary hollow pipe equipped with four evenly spaced nozzles is installed along the drum axis to supply pressurized water for washing and skin softening. The system also includes a supporting metal frame, feeding door, water collection tray, and discharge chute.

2.2. Data collection

Primary data were obtained through field visits to the Nepal Agriculture Research Council (NARC), Lalitpur, Nepal, where existing post-harvest machinery and processing challenges faced by local farmers were studied. Informal interviews and structured questionnaires were used to identify functional requirements for a small-scale root vegetable washing and peeling machine. Secondary data were collected from peer-reviewed journals, technical reports, and online databases to understand existing peeling technologies and performance benchmarks.

2.3. Design and fabrication

The design of the washing and peeling machine was developed in three stages: initial conceptual design, working design, and final fabricated design. Each stage focused on improving washing effectiveness, reducing flesh loss, and simplifying the overall structure. The initial conceptual design of the machine, which employed a vertical drum configuration, is shown in Figure 1.

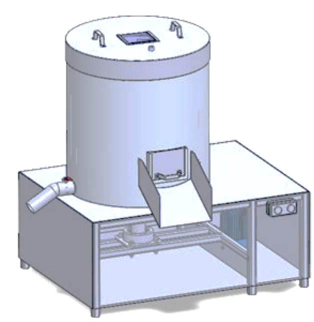

Figure 1: Conceptual design of the initial washing and peeling machine

The working design was later modified to a horizontal drum arrangement to improve tumbling and washing efficiency, as illustrated in Figure 2.

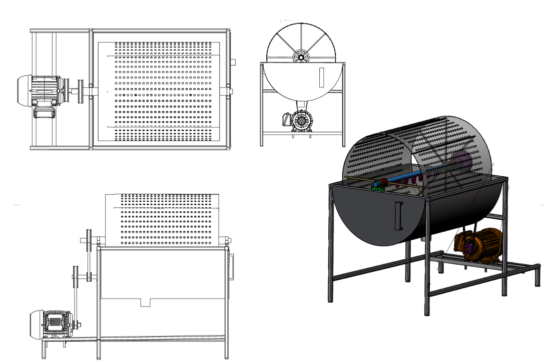

Figure 2: Working design of the washing and peeling machine

The final design incorporated compression springs as abrasive elements and included safety and maintenance

Table 1: Sample Preparation

Sample	Ginger (kg)	Potato (kg)	Total batch weight (kg)
Sample 1	1.00	1.10	2.10
Sample 2	1.46	3.54	5.00

features. A three-dimensional model of the final configuration is presented in Figure 3.

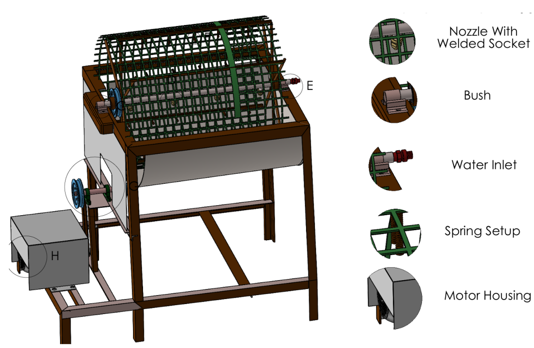

Figure 3: Three-dimensional model of the final washing–peeling machine

2.4. Performance evaluation procedure

Performance evaluation was carried out using ginger and potato samples under controlled laboratory conditions. Experiments were conducted at two drum speeds (25 rpm and 60 rpm) and two batch sizes (2.1 kg and 5 kg). Each batch was processed for 60 s. The mass of samples before and after processing was measured using a digital weighing balance to determine peeling efficiency and flesh loss. The composition and total weight of the vegetable samples used for performance evaluation are summarized in Table 1.

2.5. Performance evaluation equations

The following equations were used to evaluate machine performance:

$$\text{Peeling efficiency (\%)}\ \eta_p = \frac{W_b - W_a}{W_b} \times 100 \quad (1)$$

$$\text{Flesh loss (\%)}\ F_l = \frac{W_b - W_c}{W_b} \times 100 \quad (2)$$

where W_b is the initial weight of the sample before processing (kg),
W_a is the weight after washing and peeling (kg), and
W_c is the weight of cleaned edible product collected (kg).

3. Results and discussion

Experimental evaluation of the developed washing and peeling machine was carried out using ginger and potato samples under controlled operating conditions. The effects of drum rotational speed and batch size on washing effectiveness, peeling efficiency, and flesh loss were investigated.

3.1. Effect of Drum speed on washing and peeling performance

Figure 4 illustrates the effect of drum rotational speed on washing and peeling performance for a fixed operating time of 60 s. At a higher speed of 60 rpm, the vegetables tended to adhere to the inner surface of the drum due to increased centrifugal force. As a result, limited tumbling action occurred, leading to incomplete peeling and only partial removal of adhering soil. The measured mass of samples before and after processing at this speed showed negligible change, indicating ineffective peeling. In contrast, operation at a lower rotational speed of 25 rpm resulted in effective tumbling and repeated contact between the vegetables, compression springs, and water jets. This condition facilitated simultaneous abrasive and hydraulic action, leading to complete washing and an average peeling effectiveness of approximately 80%. These results demonstrate that lower drum speeds are more suitable for root vegetable peeling applications, as they reduce centrifugal effects and promote controlled abrasion.

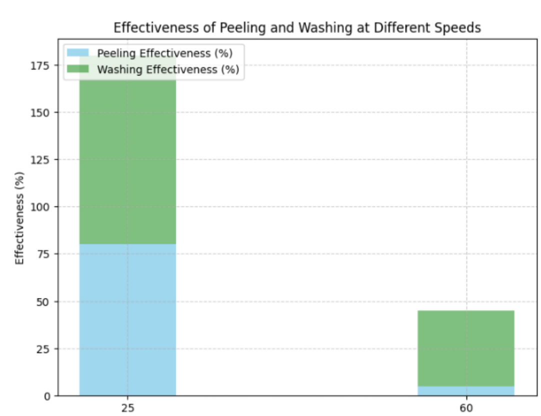

Figure 4: Effect of drum rotational speed on washing and peeling performance

Table 2: Performance results for Sample 1

Vegetable	Weight before washing (kg)	Weight after washing (kg)	Flesh loss (%)
Ginger	1.00	0.977	2.30
Potato	1.10	1.00	2.35

Table 3: Performance results for Sample 2

Vegetable	Weight before washing (kg)	Weight after washing (kg)	Flesh loss (%)
Ginger	1.46	1.43	2.05
Potato	3.54	3.46	2.25

3.2. Effect of batch size on Flesh loss

Further experiments were conducted at the optimal drum speed of 25 rpm using two batch sizes (2.1 kg and 5 kg), as summarized in Table 2 and Table 3. For the 2.1 kg batch, flesh loss values of 2.30% for ginger and 2.35% for potato were observed. When the batch size was increased to 5 kg, flesh loss decreased slightly to 2.05% for ginger and 2.25% for potato. The reduction in flesh loss at higher batch weight can be attributed to increased inter-particle cushioning among the vegetables, which reduced direct impact with the abrasive elements. This observation suggests that the proposed machine can maintain peeling effectiveness while minimizing edible material loss when operated near its designed batch capacity.

3.3. Energy consumption and cost considerations

Energy consumption for each experimental run was measured over a 60 s operating cycle and found to be approximately 0.92 kWh. Compared to conventional abrasive roller and brush-based systems reported in the literature, which often consume between 1.5 and 3.0 kWh per cycle for similar throughput, the developed machine demonstrates improved energy efficiency. Additionally, the total fabrication cost of approximately USD 240 is significantly lower than commercial washing and peeling units, which typically cost more than USD 3000 [15].

3.4. Limitations of the study

The experiments were conducted using a limited number of samples and only two drum speeds. As a result, the analysis is mainly descriptive and does not include advanced statistical methods. The long-term durability of the machine, performance with other root vegetables, and water recycling efficiency were not evaluated. These aspects should be explored in future research.

4. Conclusion

This study presented the design and performance evaluation of a low-cost washing and peeling machine for root vegetables, with ginger and potato used as test samples. The developed machine successfully integrated washing and peeling operations into a single unit using a spring-lined rotating drum and internal water nozzle system. Experimental results showed that drum rotational speed had a significant effect on performance. Operation at 25 rpm provided effective tumbling, achieving approximately 80% washing and peeling effectiveness while maintaining low flesh loss (below 2.5%) for both ginger and potato. Higher rotational speed resulted in reduced peeling performance due to centrifugal effects. The machine demonstrated low energy consumption and a fabrication cost significantly lower than that of commercial alternatives, making it suitable for small and medium-scale processing applications. Although the experimental evaluation was limited in scope, the results indicate that the proposed design offers a practical and affordable solution for post-harvest handling of root vegetables. Future work may focus on durability testing, water recirculation, and performance evaluation for other root crops.

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