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EXPERIMENTAL EVALUATION OF A FRESHROSELLE SEED SEPARATION MACHINE

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ABSTRACT

This study presents the experimental evaluation of a fresh roselle seed separation machine designed and fabricated to meet the mechanization demands of agricultural processing in Hue City, Vietnam. The experiments were conducted using fresh roselle calyces harvested in the morning to ensure sample uniformity. The results showed that the machine operated stably with an average capacity of 30 kg/h, which is highly suitable for small and medium-scale production. The seed separation rate reached 98.33%, indicating that most seed capsules were successfully separated from the calyces. The percentage of undamaged calyces after separation reached 91.39%, satisfying the aesthetic and quality requirements for high-value processed roselle products. However, the performance of the machine still partially depends on manual feeding of the calyces. Further studies shouldfocus on automating the feeding and collection processes to improve productivity and reduce manual labor, thereby enhancing the mechanization level of the local roselle processing industry.

Keywords: Roselle, seed separation machine, seed separation efficiency, product integrity, agricultural mechanization.

I. INTRODUCTION

Vietnam has a tropical monsoon climate and is endowed with abundant plant resources, with more than 12,000 species of higher plants containing biologically active natural compounds (Giang, 2017). Roselle, also known as Hibiscus sabdariffa L., belongs to the Malvaceae family. It originates from West Africa and is widely cultivated in Middle Eastern countries and tropical regions such as Indonesia, Thailand, India, Bangladesh, Malaysia, and the Philippines (Khoi et al., 2013). Studies worldwide have shown that roselle is a medicinal plant used in the treatment of hypertension (Chewonarin et al., 1999). It exhibits diuretic, choleretic, and antipyretic effects, helps reduce blood viscosity, stimulating intestinal motility, acting as a laxative, lower blood cholesterol levels, prevents coronary atherosclerosis, reduceslipid accumulation in the liver, and protect liver cells (Chi, 2005). The health-promoting properties of roselle are attributed to its high polyphenol content, in which individual compounds exhibit various bioactive functions(Peredo-Pozos et al., 2020). Roselle fruit extracts have also demonstrated antimicrobial activity against Bacillus subtilis and Escherichia coli, as well as antifungal activity againstAspergillus niger (Nguyen Van Ay et al., 2022).

In recent years, crop restructuring tailored to soil characteristics and land conditions has been strongly promoted in Thua Thien Hue Province, particularly in Phong Dien and Phu Vang districts, in order to improve agricultural. However, following the expansion of roselle cultivation, research on harvesting, preliminary processing, and value-added product development from roselle flowers has become an urgent issue. (Department of Science and Technology of Thua Thien Hue, 2021). Roselle plants were first introduced as an experimental crop in Phong An commune, Phong Dien district in 2017 on a small cultivation scale (Department of Science and Technology of Thua Thien Hue, 2021).Due to its strong adaptability to local conditions, the cultivation area has been gradually expanded by local farmers. Roselle has since been identified as a key economic crop in the agricultural development structure of Phong An commune, and products derived from roselle flowers are planned to be developed as OCOP-certified products of Phong Điền district (Le Thi Hong Phuong et al., 2021). After a period of experimental cultivation and preliminary processing, several roselle-based products have been successfully introduced to the market and have received positive consumer acceptance, leading to rapidly increasing demand. However, in current semi-processed and processed roselle products, seedremoval remains a mandatory step prior to further utilization of the calyx in product manufacturing. Although this operation is essential, it is still performed manually by farmers and small

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production units, resulting in high labor requirements, low productivity, and increased processing costs. This situation also affects harvesting schedules, increases product prices, and creates heavy dependence on local labor availability, which has become a significant practical constraint in production (Nguyen Thi Trang, 2021).

Globally, harvesting and seed separation machines for roselle have been developed. However, their large size and high costs limit their application to large-scale, centralized production systems. In Vietnam, particularly in Hue City, roselle cultivationremains relatively small-scale, and no machine prototypes or research studies on the mechanization of roselle seed separationare currently available. Therefore, experimental research on a household-scale roselle seed separation machine adapted to local production conditions in Hue City is necessary to evaluate its performance. This study aims to improve machine design and enhance the level of mechanization in roselle harvesting and processing.

II. MATERIALS AND METHODS

2.1.Experimental site

The research and experimental work were conducted at the Mechanical Workshop, Faculty of Engineering and Technology, University of Agriculture and Forestry, Hue University.

2.2. Experimental materials

The prototype of the roselleseed separation machine, designated as MTH-30 (Figure 1), was designed and fabricated at the Mechanical Workshop, Faculty of Engineering and Technology, University of Agriculture and Forestry, Hue University.

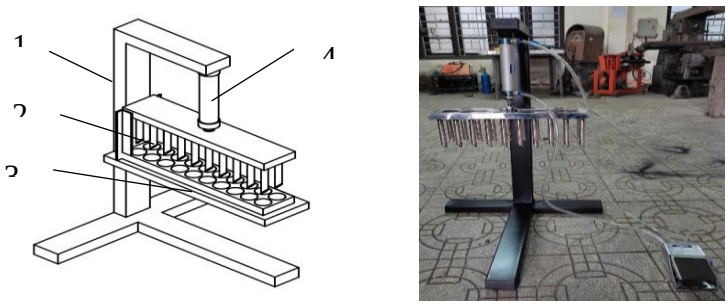

Figure 1. Design and prototype of the MTH-30 roselle seed separation machine 1. Machine frame, 2. Seed separation blade, 3. Flower feeding tray, 4. Pneumatic cylinder

The MTH-30 seed separation machine has overall dimensions of 460 x 400 x 600 mm (length x width x height). The machine frame is constructed from 60 x 30 x 2 mm hollow steel sections, while the seed separation blade is fabricated from a 12 mm diameter, 0.5 mm thick 304 stainless steel tube. Additionally, the blade mounting frame and the flower feeding tray are made from 40 x 20 x 2 mm 304 stainless steel sections. The roselleflowers used in this study were harvested from cultivation areas in Phong An and Phu Thanh communes, Thua Thien Hue province (Figure 2).

Figure 2. The roselle flowers harvested from the field for experimentation 1. Pedicel, 2. Seed capsule, 3. Seed, 4. Calyx

The seed separation principle is implemented using a blade mounting frame equipped with 20 blades, which move in a vertical reciprocating motion. The system is driven by pneumatic cylinders, enabling the blades to cut

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through the seed capsule and separate the seeds from the calyx structure.The separated seeds are discharged through the flower tray. After separation, the calyx isretained on the tray subsequently removed. The processes of loading the flowers into the tray and removingthe processed calyx are performed manually. Each operational cycle is capable of processing 20 flowers simultaneously.

During the experimental study, various instruments were used for measurement, calculation, and performance evaluation, including a Mitutoyo 500 digital caliper, a BEL electronic balance with an accuracy of 0.01g, and a Lutron MS-7002/TK-100H moisture meter.

2.3. Experimental Methods

An experimental method was employed to evaluate key performance parameters of the machine, including throughput capacity, seed separation efficiency, and product integrityafter the separation process.

2.3.1. Experimental evaluation of the machine's throughput capacity

The throughput capacity of the roselle seed separation machine is defined as the mass of fresh roselle calyces processed per unit of time. The machine capacity is calculated using the following formula:

$$N = 3600 \times \frac{m}{t} \quad (kg/h)$$

Where: N is the machine throughput capacity (kg/h); m is the mass of fresh roselle calyces processed (kg); t is the processing time (s)

2.3.2. Experimental evaluation of seed separation rate

The seed separation rate is defined as the ratio of the number of successfully processedroselle calyces to the total number of fresh calyces fed into the machine. This rate is calculated as follows:

$$T = \frac{G_2}{G_1} \times 100 \quad (\%)$$

Where: T represents the seed separation rate (%), while G1 and G2 denote the total number of fresh roselle calyces fed into the machineand the number of successfully processedcalyces, respectively.

2.3.3. Experimental evaluation of product integrity after separation

Product integrity after separation is defined as the ratio of the number of undamaged roselle calyces (free from scratches, bruising, or breakage) to the total number of fresh roselle calyces fed into the machine. This parameter is calculated using the following formula:

$$D = \frac{N_2}{N_1} \times 100 \quad (\%)$$

Where: D represents the product integrity (%), N1 denotes the initial quantity of roselle calyces fed into the machine, and N2 signifies the quantity of undamaged calyces obtained after separation.

III. RESULTS AND DISCUSSION

3.1. Physico-chemical and mechanical properties of roselle calyces

The physico-chemical properties of roselle calyces play an important role in determining their mechanical behavior during seed separation and their suitability for subsequent processing applications. In particular, parameters such as protein, total sugar content, acidity, flavonoid content, and color characteristics significantly influence tissue integrity, susceptibility to mechanical damage, and post-processing quality stability. Therefore, several key physico-chemical properties of fresh roselle calyces were experimentally analyzed, and the obtained results are presented in Table 1.

Table 1. Key physico-chemical properties of roselle calyces

No	Component	Unit	Content
1	Protein	%	1,33
2	Total sugar content	%	10,20
3	Total acid content	%	1,91
4	Total flavonoid content	mg QE/g DW	3,43
5	Hue angle	h^o	324,73

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The results presented in Table 1 indicate that fresh roselle calyces contain relatively low protein content (1.33%) but appreciable levels of total sugars (10.20%) and organic acids (1.91%), together with considerable flavonoid content and characteristic color properties.Since the seed separation process is typically performed on fresh calyces, mechanical interactions between the separation blades and the calyx structure may induce localized stress, leading to surface damage such as tearing,bruisingor micro-cracking. These defects can trigger oxidationand enzymatic browning, resulting in discoloration, and degradation ofmoisture and total sugar levels after processing. In addition, damaged tissue provides favorable conditions for microbial growth, thereby reducing the overall product quality. Therefore, the high sugar and organic acid contents, together with the delicate tissue structure of fresh roselle calyces indicate that roselle calyces are highly susceptible to oxidation and quality degradation under mechanical loading, highlighting the need for gentle handling during separation (Tran Vo Van May, 2021).

Table 2. Key mechanical properties of roselle calyces and seeds

No	Parameter	Unit	Mean value
1	Fruit mass	g	48,21
2	Calyx mass	g	27,03
3	Seed mass	g	21,18
4	Calyx/seed mass ratio	%	43,19
5	Calyx moisture content	%	90,59
6	Calyx diameter	mm	30,67
7	Calyx height	mm	45,00
8	Seed diameter	mm	19,05
9	Seed length	mm	25,56
10	Receptacle diameter	mm	25,33
11	Detachment force between the calyx and the receptacle	N	7

The results in Table 2 demonstrate that roselle calyces possess a relatively high moisture content and a delicate structural configuration, which significantly influences their mechanical response during seed separation. Therefore,the seed separation process must be performed with high precision to preserve the quality of the calyces, specifically maintaining their moisture and total sugar content. Furthermore, the separation mechanism must ensure the complete removal of the seed capsules while preventing any mechanical damage to the calyx structure (Tran Vo Van May, 2021).

3.2. Experimental results on machine performance and functional parameters

3.2.1. Evaluation of machine productivity

The productivity of the seed separation machine was experimentallyevaluated at threedifferent input mass levels of fresh roselle calyces: 1 kg, 3 kg, and 5 kg, with an initial moisture content of 90.59%. Each experimental condition was conducted in triplicate to ensure repeatability and reduce random variation. The results are summarized in Table 3. The machine achieved an average productivity of 30.54 kg/h across all tested conditions, demonstrating its suitability for household-scale processing and its potential contribution to the mechanization ofroselle processingin Hue City.

A slight decrease in productivity was observed with increasing input mass, reaching29.68 kg/h at 3 kg and 29.54 kg/h at 5 kg, respectively. This minor reduction is attributed to the manual feeding and discharge operations, whereby machine performance is influenced by operator handling during loading of calyces into the feeding tray and removal of calyces after the seed separation process. Consequently, the throughput capacity is partially constrained by operator working speed under the current experimental configuration, particularly during manual loading and unloading of calyces. The integration of an automated feeding and discharge system is therefore expected to reduce operator dependency, minimize handling-induced delays, and consequently enhance the overall and more consistent machine productivity.

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Table 3. Productivity performance of the roselle seed separation machine

Trial No	**Input mass (kg)**	**Duration (s)**	**Throughput (kg/h)**
1	1	110	32,73
2	1	114	31,58
3	1	112	32,14
AT1			32,15
4	3	369	29,27
5	3	351	30,77
6	3	363	29,75
AT3			29,93
7	5	630	28,57
8	5	615	29,27
9	5	585	30,77
AT5			29,54
Average throughput (kg/h)			**30,54**

Figure 3. Roselle calyces and seed capsules after the seed separation process

3.2.2. Evaluation of machine performance based on seed separation rate

Fresh roselle calyces harvested in the morning, with characteristics presented in Table 2, were used to evaluate the seed separation rate of the machine. After the seed separation process, the calyces remaining in the feeding tray were collected to assess the separation performance based on the successful removal of the seed capsules from the calyx structure . Each experimental trial was conducted using 20 fresh roselle calyces arranged in a single feeding tray. The experimentwas repeated nine times under identical operating conditions. The experimental results are summarized in Table 4.

Trial No	**Tray Numbers**	Number of**calyces per tray**	Number of successfully separated **calyces**	**Seed separation rate** (%)
1	Tray 1	20	20	100
2	Tray 2	20	19	95,00
3	Tray 3	20	20	100
4	Tray 4	20	19	95,00

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5	Tray 5	20	20	100
6	Tray 6	20	20	100
7	Tray 7	20	19	95,00
8	Tray 8	20	20	100
9	Tray 9	20	20	100
Mean value		**20**	**19,67**	**98,33**

Table 4. Seed separation performance of the machine

The results presented in Table 4 indicate that the machine achieved an average seed separation rate of 98.33%, demonstrating that the majority of fresh roselle seed capsules were successfully separated from the calyces during machine operation. Separation failures were primarily attributed to the small dimensional difference between the seed capsule and the calyx diameters, as well as to undersized calyces relative to the feeding tray.Consequently, some calyces weredischarged together with the seed capsules during the separation process. Therefore, implementing a pre-sorting and classification step to remove undersized calyces prior to processing could further improve the separation rate and potentially achieve complete seed separation.

3.2.3. Evaluation of machine performance based on product integrityafter seed separation

Product integrity after seed separation is an important quality indicator for ensuring complete removal of the seed capsules while minimizing mechanical damage to the roselle calyces, includingtearing, bruising, and micro-cracking. Maintaining high product integrityimproves both the quality and aesthetic appearanceof processed roselle products, thereby satisfying technical requirements for roselle processing. To evaluate product integrity, fresh roselle calyces harvested in the morning with characteristics presented in Table 2, were used in the experiments. Following the seed separation process, the calyces remaining in the feeding tray were collected to assess the degree of mechanical damage and determine the number of undamaged calyces obtained after processing. Each experimental trial was conducted using 20 fresh roselle calyces arranged in a single feeding tray and the experiment was repeated nine times under identical operating conditions. The experimental results are presented in Table 5 and Figure 4.

Table 5. Machine performance in maintaining product integrity

Trial No	**Tray Numbers**	Number of**calyces per tray**	**Number of undamaged calyces**	**Product integrity (%)**
1	Tray 1	20	19	95
2	Tray 2	20	17	85
3	Tray 3	20	18,5	92,5
4	Tray 4	20	18	90
5	Tray 5	20	19	95
6	Tray 6	20	18,5	92,5
7	Tray 7	20	19	95
8	Tray 8	20	18	90
9	Tray 9	20	17,5	87,5
Mean value		**20**	**18,28**	**91,39**

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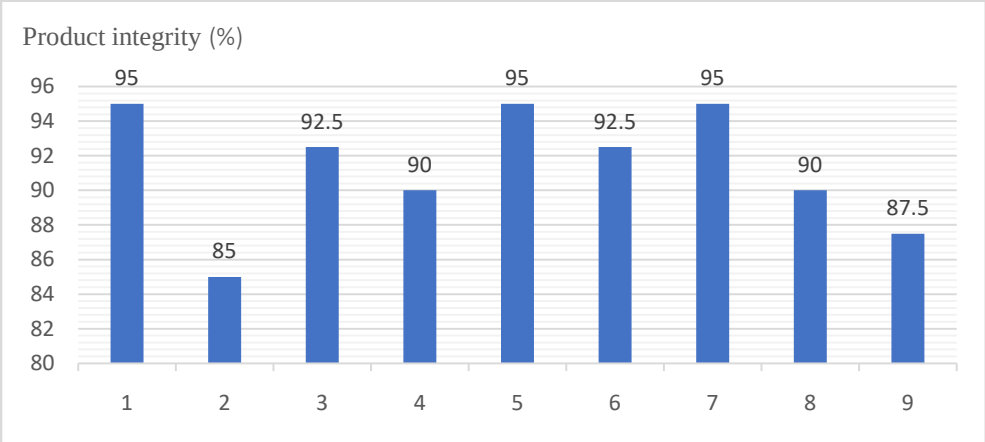

Figure 4. Product integrity results under machine operation

Data presented in Table 5 and Figure 4 indicate that product integrityafter the seed separation process ranged from 85.00% to 92.50%, with an average product integrity of 91.39%. Product integrity was strongly influenced by the manual placement of roselle calyces into the feeding tray. Improper alignment of the calyces during loading into the feeding tray increased the occurrence of mechanical damage, including tearing, bruising, and micro-cracking of the processed calyces.

IV. CONCLUSION

The experimental results demonstrated that the developed fresh roselle seed separationmachinesatisfied the intended operational requirements for roselle cultivated in Hue City, Vietnam. The machine operated stably with anaverage productivity of approximately 30 kg/h, making it suitable for small and medium-scale roselle processing systems.A seed separation rate of 98.33% was achieved, indicating high effectiveness in removing seed capsules from roselle calyces and improving the quality of raw materials for subsequent processing. In addition, the average product integrity reached 91.39%, satisfying the technical requirements for the production of high-value roselle-based products. However, further studiesare required to improve the automationof feeding and product discharge operations in order to enhance machine productivity, improve processing quality, and reduce dependency on manual labor. Such improvements would contribute to increasing the level of mechanization in roselle production and processing systemsin HueCity in the future.

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