Enhancing Puffed Rice Production in Thailand: A Performance Comparison of Traditional and Mechanical Methods

Pracha Bunyawanichakul
Department of Mechanical Engineering, Faculty of Engineering, Srinakharinwirot University, Nakhonnayok, Thailand
prachabu@g.swu.ac.th

Krissadang Sookramoon
Department of Mechanical Engineering Technology, Faculty of Industrial Technology, Valaya Alongkorn Rajabhat University under the Royal Patronage, Pathum Thani, Thailand
krissadang.sook@vru.ac.th (corresponding author)

Manunya Khamwachirapitak
Department of Home Economics, Faculty of Science and Technology, Valaya Alongkorn Rajabhat University under the Royal Patronage, Pathum Thani, Thailand
manunya@vru.ac.th

Yosita Charoensiri
Department of Industrial Electrical Technology, Faculty of Industrial Technology, Valaya Alongkorn Rajabhat University under the Royal Patronage, Pathum Thani, Thailand
yosita.cha@vru.ac.th

Aucha Posuwan
Faculty of Industrial Technology, Valaya Alongkorn Rajabhat University under the Royal Patronage, Pathum Thani, Thailand
aucha.pro@vru.ac.th

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ABSTRACT

This study compares traditional manual and modern mechanical methods of producing puffed rice in Thailand, in order to improve the efficiency and quality of the process and increase its scalability. Thailand is one of the world's leading rice producers, but the industry faces challenges due to limited mechanization, high labor intensity, and underdeveloped value-added applications. Experimental trials were conducted using selected rice varieties with different grain sizes and amylose contents. The findings showed that rice with higher length-to-width ratios and amylose contents had better results. The mechanical method exhibited a higher average expansion ratio (12.50) than the manual one (11.80), and doubled production capacity (400 kg/day versus 200 kg/day). Furthermore, the mechanical method achieved a production rate of 55.81 kg/h, a lower loss rate of 7.67%, and batch time reduced to 10 min, with no significant taste quality differences. Using salt soaking and maintaining an optimal moisture content of 10%-13% improved puffing consistency. This research introduces a novel, semi-automatic, double-head puffing prototype that integrates electro-pneumatic actuation and a Programmable Logic Controller (PLC), enabling synchronized, continuous puffing operations. This increases automation and labor efficiency beyond the capabilities of conventional single-head machines. Although traditional methods are appropriate for small-scale use, the mechanical system offers significant advantages in consistency, and ergonomics.

Keywords-puff rice production; processing efficiency; rice variety; expansion ratio; mechanical puffing

I. INTRODUCTION

Thailand is one of the world's leading producers and exporters of rice, with varieties, such as jasmine (hom mali), glutinous, and whole-grain products. Thai rice grows in rain-fed paddies, where climatic conditions, such as annual rainfall (exceeding 1,000 mm) and temperatures above 25° C, favor cultivation, offering moderate levels of protein, zinc, and niacin while being low in micronutrients, like calcium and iron. Puffed rice (Khao Tok or Khao Mao) is found in temple offerings and festivals and is becoming popular in modern snack products. The traditional puffing process includes several manual steps, such as soaking, drying, and roasting the rice in hot sand or heated pans, which is a time-consuming method. Modern puffing machines are efficient and capable of handling high volumes (100–200 kg/h), but are expensive for small-scale farmers. Traditional puffed rice is made by heating steam-conditioned rice, causing the moisture and starch to expand rapidly, forming light, crisp grains, which are used in sweet snacks, cereals, and energy bars. The Thai puffed rice industry faces several challenges, including weak ties between farmers and industries, hindering value addition. However, strengthening networks between farmers and retailers, and modernizing the branding of traditional Thai snacks, focusing on food safety, can help the industry expand into new domestic and global markets. Authors in [1], noted that rice is a common food for a great number of the world's population and a key source of energy, containing carbohydrates, a significant number of calories, and all the essential amino acids needed by the human body. Authors in [2] stated that as the global population continues to grow, so does the demand for rice, for both cooked and processed products. Authors in [3] identified critical chemical properties, such as amylose content and gelatinization temperature, that influence puffing. Authors in [4] examined the role of pericarp thickness and other physical characteristics affecting microwave popping, concluding that factors, such as hardness and moisture distribution, are crucial for puffing. Authors in [5] found that low-amylose rice varieties, such as RD6 and RD10, with a moisture content of 13%, expanded best at 700 W-800 W. Authors in [6] showed that moisture content, salt concentration, and microwave power significantly affect the expansion ratio, hardness, and puffing, concluding that optimal results were achieved at approximately 13% moisture content and moderate salt levels. Authors in [7] presented a modeling work on a pneumatic rice puffing machine, studying the heat transfer process during fluidization, and revealing that an air temperature of 240 °C-270 °C for 7–9.7 s was ideal for achieving high expansion and good product color. Despite variations in air temperature, the surface temperature of the rice grain remained stable at approximately 170°C during puffing. Authors in [8] described how puffing conditions affect expansion, hardness, and nutrient retention, whereas authors in [9] showed that infrared puffing at 550 W and a distance of 10 cm optimized the puffing volume while reducing density. Authors in [10] developed antioxidant-rich puffed snacks using rice flour and corn grits, while authors in [11] produced gluten-free extruded rice snacks using flour from brown jasmine rice, black glutinous rice, and rice berry. A 1:1:1 flour blend (formulation 7) achieved the highest sensory scores, along with increased antioxidant levels and a dietary fiber content of approximately 4.11%. A collaboration between the Hin Kling Community Enterprise, Chiang Mai Rajabhat University (CMRU), and PTT, converted rice berry into a marketable health product, using the four Ps model: process, product, packaging, and product marketing [12]. This product offers biofunctional benefits, an extended shelf life, and a lower sugar content. Authors in [13] showed that puffed rice could be used as a material for 3D food printing, whereas authors in [14] presented the significant growth of the retail market for puffed wheat and rice in 2024, due to health trends, product innovation, and the increased demand for organic and easily accessible products. Biodegradable packaging and online sales, improved consumer engagement, playing a crucial role to this increase. Authors in [15] focused on predicting heat penetration in thermal systems, particularly during ohmic heating of honey, by using AI, such as Long Short-Term Memory (LSTM) neural networks, to model and predict this process. This approach addresses a critical need in food processing and other thermal applications by maintaining product quality and optimizing energy usage. According to [16, 17], food processing machines are one of the largest and fastest-growing subsectors of machinery manufacturing, driven by the global demand for efficiency, automation, and hygiene in food production. This study aims to evaluate and improve the puffed rice production process in Thailand by comparing traditional and modern methods, improving production efficiency, quality, and scalability in order to promote sustainable practices and added value, particularly for small-scale puffed rice food industries.

II. MATERIALS AND METHOD

A. *Research Design and Methodology*

This study used an experimental, comparative design to evaluate the differences in performance between traditional, manual, and modern, mechanical puffing methods, examining expansion ratio, production capacity, material loss rate, and operational efficiency, in three phases:

1) *Selection and Preparation of Rice Samples*

The varieties commonly used in Thai puffed rice production, particularly those with varying amylose content and length-to-width ratios, were acquired from local suppliers. The rice was cleaned, soaked in saltwater (1.5%–2% w/v), and dried to reach target moisture levels of 10%–13%. Authors in [5, 6] found that these parameters significantly impact puffing expansion and texture.

2) *Experimental Trials Using Two Puffing Methods*

The study compared two puffing techniques to evaluate their performance and efficiency: the traditional method (the control group) required sand-roasting rice in wood-fired pans, a common manual process. The experimental group used a semi-automatic double-head puffing machine, which was created for this study to improve consistency, reduce labor, and increase production capacity.

3) *Performance Evaluation Metrics*

Key performance indicators included the expansion ratio (the volume change before and after puffing), production capacity (kg/h), the material loss rate (the percentage of raw material lost per batch), puffing time (min/batch), energy consumption (kWh/ batch, measured using a watt-hour meter), and sensory consistency (visual appearance, crispness, and color). A paired-sample t-test was conducted at a significance level of $\alpha = 0.05$ to determine statistical differences between the two methods.

B. Prototype Engineering Design and Machine Construction

A semi-automatic double-head puffing prototype was designed and constructed to support the mechanical puffing process. The machine is equipped with pneumatic actuators, programmable control logic, heating systems, and safety features that align with the standards for small-scale food machinery [1, 2]:

1) Mechanical Frame and Structural Components

The machine's frame is made of food-grade stainless steel (SUS304) to withstand heat and promote hygiene. The double-head design enables two rice portions to be puffed simultaneously, boosting productivity without increasing the machine's footprint. The frame was designed to be stable and strong enough to support the weight of all components, as shown in Figure 1.

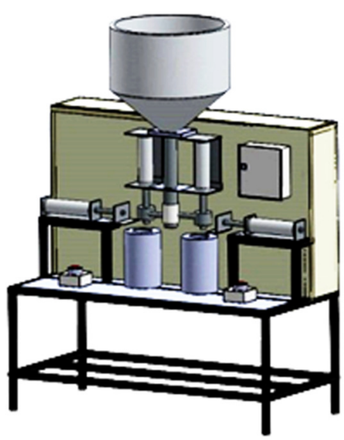

Fig. 1. Prototype for the semi-automatic double-head rice puffing machine.

The two heads were designed to apply consistent pressure and allow for controlled force. A pneumatic system was integrated to control head movement, using a continuous electrical circuit (A+ B+ A- B-) to increase the efficiency of producing puffed rice, as depicted in Figure 2.

2) Pneumatic Actuation System

A continuous electro-pneumatic sequence (A+B+A−B−) controlled the two pneumatic cylinders. Each cylinder head applies controlled compression to rice grains, creating the rapid pressure release conditions necessary for puffing. To ensure synchronized timing between the cylinders, solenoid 5/2-directional control valves and limit switches were installed, allowing for simple reprogramming of the puffing cycle based on future process modifications.

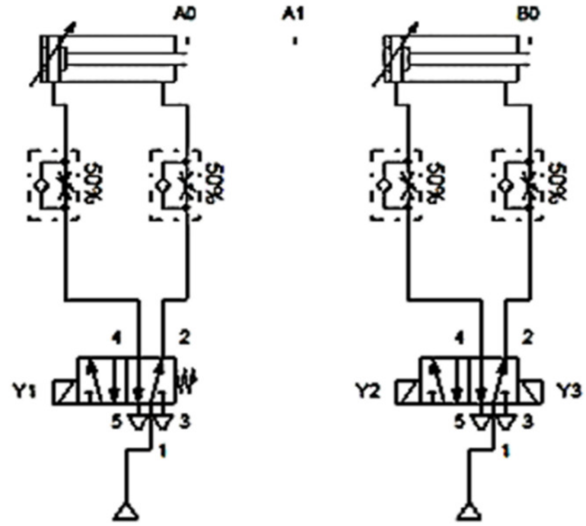

Fig. 2. Pneumatic power circuit.

3) Heating and Temperature Control

Each puffing chamber was equipped with 750 W band heaters and monitored using thermocouples connected to a Proportional, Integral, and Derivative (PID) temperature controller. Stable heating at 220 °C –250 °C was maintained to ensure rapid heat transfer to the rice grains.

4) Ventilation and Moisture Removal

A small-scale exhaust ventilation system with heat-resistant fans was used to expel steam during the puffing process. This prevented moisture accumulation, affecting the texture of the product.

5) Electrical Control System

A PLC coordinated the puffing cycles, including temperature regulation, timing, and pneumatic actuation. Safety measures and an emergency stop system were added to meet the basic industrial food safety standards.

6) Instrumentation and Data Collection

In order to monitor the performance and data collection, digital thermocouples for real-time temperature measurement, a watt-hour meter for energy consumption analysis, and a moisture analyzer for consistent rice moisture content maintenance were used. Additionally, a digital scale and calipers provided accurate measurements of weight and expansion ratios, and a stopwatch timed the puffing process precisely.

C. Puffing Procedure

For each method, the rice batches were prepared with 12% moisture and puffed under consistent conditions. In the mechanical system, one puffing cycle lasted approximately 10 min. The input - output weight, and expansion size of each sample were recorded for analysis. The traditional method followed the standard practice of sand roasting with wood heat and manual stirring and cooling between cycles. The experimental rice puffing procedure is based on the principle of heat convection, in which heat is transferred from a heater to the rice to induce puffing. A prototype puffing machine was used to produce standard rice puff products and modified versions were designed to meet the dietary needs of elderly consumers by adjusting the ingredients and sizes. Comprehensive data collection was carried out during the process, including measurements of the puff size, weight, and forming time. Additionally, defective pieces were analyzed to identify the underlying causes and improve the machine's overall performance and consistency, as portrayed in Figures 3-5. Puffed rice is produced through a process that begins with cleaning and soaking the rice kernels. Next, the rice is dried and rapidly exposed to high heat in a process called puffing, which causes the grains to expand. Finally, the puffed rice is cooled and packaged, as presented in Figure 6.

Fig. 3. Semi-automatic double-head rice puffing machine.

Fig. 4. Puffed rice weight measurement.

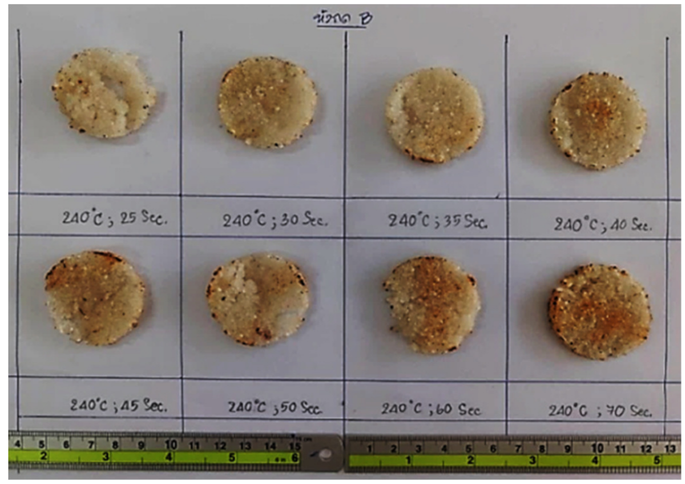

Fig. 5. Puffed rice production experiment.

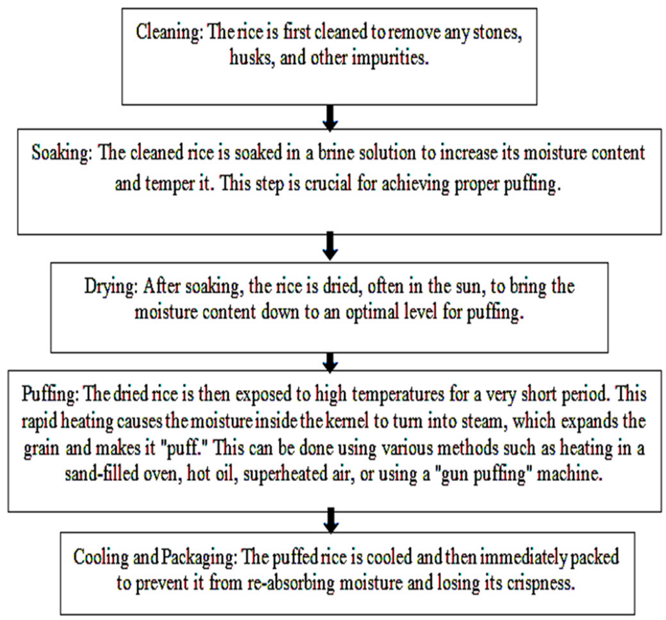

Fig. 6. Puff rice production process.

The traditional sand-roasting method requires a lot of manual labor, which results in limited and inconsistent production capacity. Each batch yields 0.3 kg-0.5 kg and takes 15 min-20 min to complete, including preparation and sifting the sand. Depending on the operator's skill and stamina, the estimated hourly output is 1 kg-2 kg. Notably, production is highly labor-dependent, with a significant raw material loss due to burning or breakage.

III. RESULTS AND DISCUSSION

A. Comparative Production Performance

The experimental data revealed that the mechanical puffing method substantially improved both efficiency and consistency compared with the traditional manual method. Table I summarizes the key performance metrics across six experimental batches. Each machine can process 10 kg - 20 kg of rice per batch in 5 min - 10 min, resulting in an hourly output of 60 kg - 90 kg. This high, consistent production rate is maintained throughout operation with minimal raw material loss and effective control over product quality, including size, color, and crispness.

TABLE I. PRODUCTION DATA

Batch number	Production mmethod	Raw material quantity (kg)	Output quantity (kg)	Production time (min)	Loss rate (%)	Production capacity (kg/h)
1	Conventional	0.5	0.38	20	24%	1.14
2	Conventional	0.5	0.35	22	30%	0.95
3	Conventional	0.5	0.39	18	22%	1.30
4	Modern	10.0	9.20	10	8%	55.20
5	Modern	10.0	9.35	9	6.5%	62.33
6	Modern	10.0	9.15	11	8.5%	49.91

The mechanical system achieved an average production capacity of 55.81 kg/h, which is significantly higher than the traditional method's average of 1.13 kg/h. Additionally, the loss rate from 25.33% using the traditional method decreased to 7.67% with the mechanical method.

- Loss rate is defined by:

$$Production\ capacity = (Raw\ Material\ Quantity - Output\ Quantity)/Raw\ Material\ Quantity \times 100 \quad (1)$$

resulting: 24%

- Production capacity is the maximum output a production system can achieve under normal operating conditions within a specified time frame:

$$Production\ capacity = (Output\ Quantity/Production\ Time) \times 60 \quad (2)$$

resulting: 1.14 kg/h.

Figure 7 shows the production times for samples 1-6, with 4-6, using the modern production method, requiring significantly less time—ranging from 9 min to 11 min—compared to samples 1-3, which used the conventional method that took between 18 min and 22 min. This demonstrates the increased efficiency of the modern method, which contributes to a higher overall productivity.

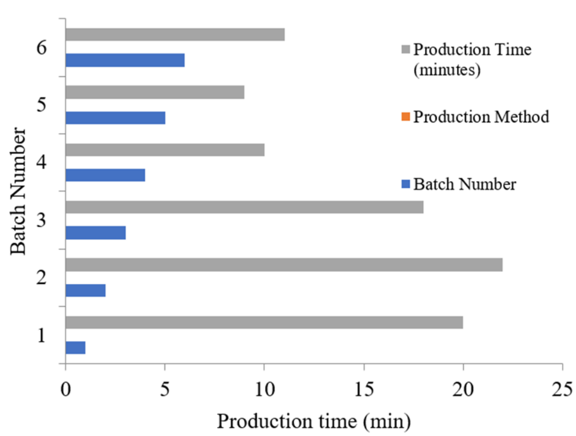

Fig. 7. Production time comparison.

The data indicate that batches 3-6 used more raw material and produced higher output quantities than batches 1-3, as shown in Figure 8. Specifically, samples 1-3 used 0.5 kg of raw material per batch and produced quantities from 0.35 kg to 0.39 kg, while samples 3-6 used 1.0 kg of raw material per batch, and produced quantities ranging from 0.91 kg to 0.93 kg. In contrast, batches 3-6, particularly batches 4-6, which employed the modern method, used 10 kg of raw material and achieved significantly higher outputs, ranging from 9.15 kg to 9.35 kg. These results suggest that the modern method can handle larger sizes and enhance the overall production, making it more suitable for high-volume processes.

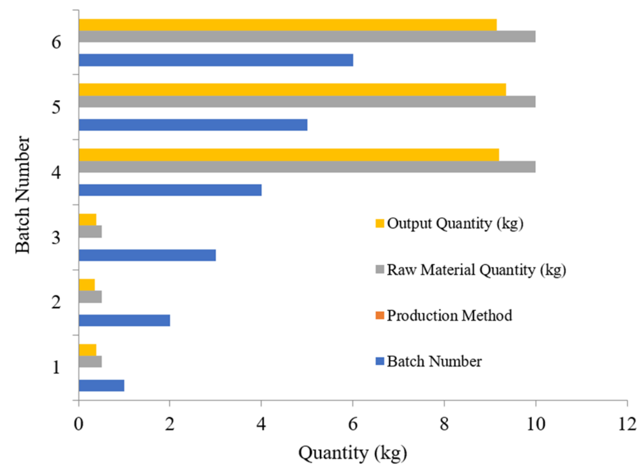

Fig. 8. Quantity comparison.

The results of the modern method used in samples 4-6 show a significant increase in production capacity and a notable reduction in loss rates, ranging from 6.5% to 8.5%, in contrast to the higher rates observed in conventional samples. At the same time, production capacity dramatically improves to 49.91 kg/h-62.33 kg/h, as shown in Figures 9 and 10. The modern method's ability to reduce waste and increase output highlights its efficiency and scalability, making it a preferable choice for maximizing productivity and minimizing resource wastage.

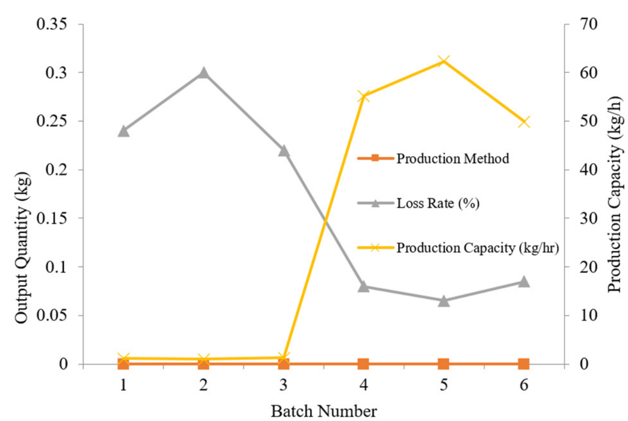

Fig. 9. Production capacity of each batch.

B. Statistical Analysis

A paired t-test was performed to validate the significance of the observed differences in production capacity. The results revealed a statistically significant difference in production capacity between the manual puffing method (M = 1.14 kg/h, SD = 0.11) and the mechanical puffing method (M = 55.82 kg/h, SD = 0.29): $t(4) = -343.09$, $p < 0.001$. This confirms the superior efficiency of the mechanical process, as shown in Table II.

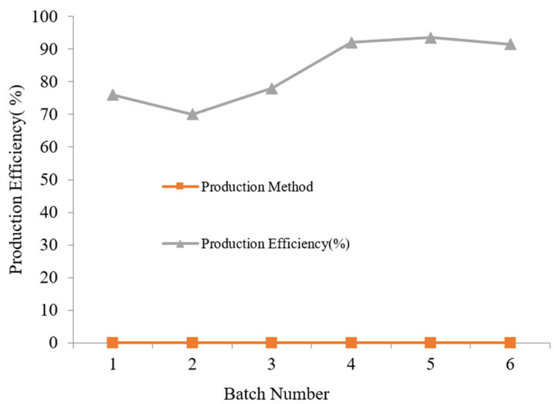

Fig. 10. Production efficiency (%) of each batch comparison.

TABLE II. PAIRED T-TEST RESULTS FOR PRODUCTION CAPACITY

	Variable 1	**Variable 2**
Mean	1.14	55.82
Variance	0.013	0.082
Observations	5	5
Pearson correlation	-0.4900511	
Hypothesized mean difference	0	
df	4	
t Stat	-343.09283	
P(T<=t) one-tail	2.165E-10	
t Critical one-tail	2.1318468	
P(T<=t) two-tail	4.33E-10	
t Critical two-tail	2.7764451	

Since the p-value is significantly lower than 0.05, the results confirm that the mechanical method provides a statistically significant improvement in production throughput. To assess external validity, the present study compared the system's performance with existing industry data from puffed grain equipment manufacturers and recent scientific studies, as presented in Table III.

TABLE III. COMPARISON WITH EXTERNAL INDUSTRY DATA

Parameter	**Traditional**	**Mechanical (this study)**	**Industry benchmark [14]**
Capacity (kg/h)	1.13	55.81	50–100
Loss rate (%)	25.33	7.67	<10
Expansion ratio	11.80	12.50	12–13
Time per batch (min)	20	10	8–12

C. Comparison with Industry Benchmarks

To evaluate the system's validity, its performance was compared with existing industry data from puffed grain equipment manufacturers and recent scientific studies. The test results confirm that the modern puff rice production method is vastly superior to conventional approaches based on a comparison with external industry data. The modern method's capacity of 55.81 kg/h is consistent with mechanical machine output, and its impressively low loss rate of 7.67% even surpasses some published benchmarks. In contrast, the conventional method's capacity of 1.13 kg/h performs well below the 50 kg/h typically reported for traditional methods, highlighting its inefficiency in terms of both speed and yield compared to this modern process and the general industry standards. The results demonstrate that the developed prototype meets or exceeds standard industry metrics for small-to-medium puffed rice processing systems, particularly with regard to minimizing raw material waste and maintaining consistent output.

IV. CONCLUSIONS

This study developed and evaluated a mechanical puffing system for rice grains, achieving a processing capacity of 55 kg/h, representing a 48-fold increase in throughput compared to traditional manual methods. The system maintained a loss rate below 8%, aligning with industry standards for puffed grain production. Additionally, it produced high-quality, uniform products with expansion ratios of up to 12.5, ensuring its suitability for semi-industrial applications. Key innovations included a heat chamber designed for uniform thermal distribution, a stirring mechanism that minimizes burning, and an automated discharge system that enhances operational safety and efficiency. When compared to commercial systems and previous studies, the prototype showed competitive performance, especially in low-resource settings where affordability, energy efficiency, and mechanical simplicity are important, such as in small-scale Thai food enterprises or rural areas. Future improvements include automating the input and output systems, optimizing energy use with electric or biomass heating, and scaling up by deploying multiple units in parallel. Smart monitoring via the Internet of Things (IoT) and integration with commercial packaging will further enhance quality.

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