



Process Optimization and Quality Characteristics of Sheet-Type Puffed Rice from Glutinous and Pathum Thani Rice Flour

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Abstract: This study evaluated the effects of formulation ratio (glutinous rice: Pathum Thani rice flour) under controlled moisture conditioning (13–19% w.b.) on the physical, physicochemical, and mechanical properties of sheet-type puffed rice produced using a dual-head puffing machine. The investigated parameters included expansion ratio, color (L^* , a^* , b^*), moisture content, water activity (a_w), hardness, adhesiveness, and fracturability. Statistical analysis revealed that formulation ratio significantly affected hardness ($p < 0.05$), whereas no significant differences were observed in expansion ratio, color, moisture content, or water activity between treatments ($p > 0.05$). Formula S1 (40:60) exhibited higher hardness (28.52 N) and minimal adhesiveness and fracturability, while S2 (50:50) produced a softer product (20.49 N) with greater variability in fracturability. Both formulations showed comparable expansion ratios (3.85 for S1 and 3.93 for S2) and low water activity values (0.243–0.268 for S1 and 0.243–0.251 for S2). These results indicate that formulation ratio plays a critical role in determining the mechanical properties of sheet-type puffed rice and may be adjusted to achieve desired textural characteristics.

Keywords: Puffed rice; expansion ratio; puffing conditions

1. Introduction

Rice is one of the most important staple crops globally and plays a central role in food security, particularly in Asia. Beyond conventional consumption as cooked milled rice, increasing consumer demand for convenient, ready-to-eat, and value-added products has driven rapid development in rice-based processed foods. Among these, puffed rice products represent a promising category due to their low fat content, expanded structure, crisp texture, and long shelf stability.

Puffing is a thermo-mechanical process that involves rapid heating under pressure followed by sudden pressure release, leading to moisture vaporization and expansion of the starch matrix. The mechanism has been widely described in cereal systems and is comparable to popcorn popping, in which internal steam pressure exceeds structural resistance, leading to explosive expansion [8]. During puffing, starch gelatinization and subsequent structural setting determine final product texture and integrity.

Factors Influencing Puffing Performance

Previous studies have identified several key factors governing puffing quality, including moisture content, temperature, processing time, and raw material composition. Moisture content is considered one of the most critical parameters. Insufficient moisture limits steam generation and reduces expansion, while excessive moisture may prevent complete structural setting [3]. Optimal moisture levels vary depending on rice variety and processing conditions. Temperature and heating duration significantly affect the expansion ratio and mechanical properties. Higher temperatures generally promote greater expansion due to increased vapor pressure, but excessive heating may cause structural collapse or over-browning. The balance between heat transfer and moisture diffusion is therefore essential. Rice composition and starch characteristics also play a fundamental role. Amylose content influences gel formation, rigidity, and expansion potential [16]. Variations in starch structure and flour composition can alter mechanical resistance and textural outcomes in puffed cereal products [19].

Mechanical and Quality Evaluation of Puffed Products

Product quality in puffed cereals is typically assessed using expansion ratio, color parameters, moisture content, water activity (aw), and mechanical properties such as hardness and fracturability. Texture profile analysis (TPA) provides a quantitative measurement of structural strength and crispness. Water activity is particularly important for predicting microbiological stability and shelf-life potential, with values below 0.6 generally considered safe for dry snack products.

Recent advances in extrusion and thermo-mechanical processing have emphasized the relationship between formulation variables and structural properties of expanded snacks. However, most studies focus on extrusion systems, while limited research has addressed sheet-type puffed rice produced using mold-based or dual-head puffing machines.

Research Gap

Despite extensive literature on cereal extrusion and rice puffing mechanisms, there is limited information regarding:

- The combined effect of glutinous rice and rice flour formulations on sheet-type puffed rice structure
- Mechanical property differentiation between formulation ratios
- Quality evaluation under controlled dual-head puffing systems
- Optimization of formulation for structural integrity versus softness preference

Furthermore, few studies have systematically evaluated mechanical properties (hardness, adhesiveness, fracturability) alongside physicochemical parameters in Thai rice varieties.

Processed Rice in Thailand – Value Addition from Key Agricultural Commodities

Thailand, as one of the world's major producers and exporters of rice, maintains a deep-rooted connection with rice across multiple dimensions—not only as a dietary staple that sustains its population but also as a foundation of its economy, society, and culture. However, amid global changes, evolving consumer behavior, and rising demand for convenient, value-added products, rice processing has become increasingly important in Thailand. Where once rice consumption was mostly in the form of cooked milled rice, the modern rice-processing industry in Thailand has advanced rapidly. Rice is now used as a raw material in the production of a wide range of products that cater to diverse consumer needs, including ready-to-eat foods, snacks, beverages, and even non-food items. Processing not only extends shelf life and enhances convenience but also adds significant value to the nation's primary agricultural outputs, creating business opportunities and strengthening the economy as a whole. Continuous research and development in rice processing technology is therefore essential to improve the competitiveness of Thailand's rice industry in global markets, while also supporting the development of high-quality, innovative products that meet changing consumer demands and promote efficient, sustainable use of resources. This article explores the current state of Thailand's processed rice industry, its potential, challenges, and future development directions.

Puffed Rice Products – An Innovative Application of Rice Processing

Puffed rice is a product derived from rice processing, produced by applying heat under high pressure, which causes the rice kernels to expand and bind together without the need for additional ingredients. The resulting product is typically flat, airy, crispy, and low in calories, which has contributed to its popularity in countries such as the United States, Japan, India, and Australia [1]. The puffing mechanism described by Hsieh and Luh is based on the rapid expansion of steam within the voids of the rice grain [2]. Under heat and pressure, the rice cooks and its internal moisture vaporizes. When pressure is suddenly released, rapid steam expansion forces the rice to expand according to the mold shape, producing a crispy texture. Several factors, including initial moisture content, temperature, and heating time, influence puffing performance. Rice with insufficient moisture exhibits poor puffing characteristics [3]. An optimal temperature range of 200–270 °C has been suggested, with higher temperatures generally promoting greater expansion [4]. Experimental evaluation at 200–230 °C demonstrated that 230 °C produced superior puffing performance [1]. Extended heating duration may also enhance moisture absorption and puffing quality [1], [5], [6]. Puffing quality is commonly evaluated using puffing ability and expansion ratio.

Puffing Methods in Thailand

In Thailand, traditional puffed rice products are produced by roasting rice with hot sand (khao tok) or deep-frying (khao tan). However, deep-frying increases fat content and may accelerate rancidity during storage [7], making it less suitable for health-conscious consumers. Consequently, sheet-type ready-to-eat puffed rice products have emerged as a promising alternative. Puffed rice is generally produced through high temperature and pressure, leading to starch gelatinization and steam-induced expansion within the grain [3, 8]. Several studies have examined factors affecting puffing performance, including rice variety, grain moisture content, heating temperature, and puffing method [9-11]. The popcorn popping mechanism described by Hoseney et al. shares similarities with rice puffing, where internal moisture vaporization generates pressure that results in explosive expansion upon release [8]. Moisture content is a critical variable; insufficient moisture reduces puffing efficiency [3]. Moraru and Kokini emphasized the importance of nucleation and expansion dynamics during extrusion and microwave processing, highlighting the roles of moisture and temperature control [12]. Microwave-assisted puffing has also been investigated and shown to influence puff quality and texture [13-14]. Grain type and starch composition significantly affect puffing behavior. Amylose content influences texture and expansion potential [15-16]. Varietal differences contribute to variations in cooking and textural properties [17]. Extrusion cooking modifies carbohydrate structures, thereby affecting puffability [18]. Physical properties such as hardness, expansion volume, and surface color are widely used as quality indicators in puffed cereal products [19-20]. Puffing alters the ultrastructure of cereal grains, influencing texture and expansion performance [19]. Grain physical characteristics further distinguish between good and poor expansion outcomes [11]. Nutritional aspects of puffed rice products have also been emphasized. Whole-grain labeling and its associated health implications have been highlighted in previous studies [22-23]. Standard analytical methods, such as those provided by AOAC, are commonly used to ensure consistent quality measurement in puffed grain research [24]. Collectively, these studies provide foundational knowledge on puffing mechanisms, influencing parameters, and evaluation techniques. The integration of moisture content, temperature, rice variety, and textural assessment is essential for optimizing modern puffing technologies, including the dual-head puffing system applied in the present study.

Therefore, this study aimed to evaluate the effect of formulation ratio (glutinous rice: Pathum Thani rice flour) under controlled moisture conditioning (13–19% w.b) on the physical, physicochemical, and mechanical properties of sheet-type puffed rice produced using a dual-head puffing machine. The study focused on expansion ratio, color (L^* , a^* , b^*), moisture content, water activity, hardness, adhesiveness, and fracturability to identify the formulation that provides optimal structural stability and desirable texture characteristics. Based on the machine developed in this study, the typical puffed rice production process consists of six main steps. First, rice preparation involves selecting the desired variety (Pathum Thani 1) and adjusting its moisture content to 13–19% (wet basis) by adding a calculated amount of water, followed by storing the rice at 4°C for 24 hours in a sealed container to ensure uniform moisture distribution. Next, during machine setup, the puffing machine is powered on, with mold temperatures set between 220–240°C and

heating duration adjusted to 3–7 seconds. In the molding and heating stage, approximately 5 grams of prepared rice is placed into the lower mold, and the upper mold is closed to create a sealed chamber. During puffing, the rice undergoes rapid internal steam pressure buildup, leading to gelatinization; when the mold is suddenly opened, the quick pressure drop causes the steam to escape instantly, expanding the rice and bonding it into a sheet. Then, in the product removal step, the puffed rice sheet is carefully removed from the mold. Finally, quality evaluation is conducted to assess product characteristics such as size, volume, expansion ratio, color, and texture to ensure consistent product quality.

2. Methodology

Materials and Methods

2.1 Experimental Design

A completely randomized design (CRD) was employed to evaluate the effects of formulation ratio and initial moisture content on the physical and mechanical properties of sheet-type puffed rice.

Two formulation ratios of glutinous rice to Pathum Thani rice flour were investigated:

- S1 (40:60, w/w)
- S2 (50:50, w/w)

The initial moisture content (13–19% w.b.) was adjusted during preliminary trials to ensure adequate puffing performance. In the main experiment, moisture content was standardized prior to puffing to eliminate it as a confounding variable. Each treatment was independently produced under identical processing conditions (220 °C for 75 s). The selected processing condition (220 °C for 75 s) was determined based on preliminary trials and literature suggesting optimal puffing performance within 200–240 °C [4, 11]. Physicochemical analyses (moisture content, water activity, and color) were conducted in triplicate ($n = 3$), while mechanical properties were measured using ten replicates per formulation ($n = 10$). Sample size was selected based on previous puffed cereal studies [19, 21]. Statistical comparisons between S1 and S2 were performed using an independent samples t-test at a significance level of $p < 0.05$. Temperatures below 200 °C resulted in insufficient expansion, while temperatures above 240 °C caused surface over-browning and structural collapse during pilot testing. A heating duration of 75 s was found sufficient to achieve complete starch gelatinization and internal steam pressure development without excessive moisture loss. The sample mass (4 g per sheet) was standardized to ensure uniform heat transfer and consistent mold filling, minimizing variability in expansion and mechanical measurements. These controlled parameters were maintained throughout the experiment to isolate the effect of formulation ratio and ensure reproducibility of results.

2.2 Raw Materials and Sample Preparation

Glutinous rice (Khao Niao Khiao Ngu) was soaked in hot water at a 1:4 (rice:water, w/v) ratio in a sealed container at room temperature for 4 h to ensure uniform hydration. The soaked rice was drained for 10 min before mixing. Hom Pathum Thani 1 rice flour (60-mesh particle size, 20% w.b. moisture content) was blended with the hydrated glutinous rice according to the designated formulation ratios (S1 or S2). Vegetable oil was incorporated as a binding agent. The mixture was manually homogenized and allowed to rest for 10 min to stabilize moisture distribution before molding.

2.3 Puffed Rice Production

Approximately 4 g of the prepared mixture was weighed using a digital balance (± 0.01 g accuracy) and placed into a dual-head puffing machine. Puffing was conducted at 220 °C for 75 s. During processing, the mixture was subjected to high temperature and pressure within a closed mold. Upon sudden mold opening, rapid steam expansion led to the formation of sheet-like puffed rice. All samples were cooled to room temperature before quality analysis.

2.4 Physical Characterization

2.4.1 Dimensional Measurements

The width and thickness of the puffed rice sheets were measured using a digital Vernier caliper (± 0.01 mm). Ten samples per formulation were analyzed.

2.4.2 Weight and Volume

Individual sheet weight was recorded using a digital balance (± 0.01 g). Volume was determined using the displacement method described by Sharma (2012). The expansion ratio was calculated as the ratio of the puffed volume to the initial sample volume.

2.5 Color Measurement

Surface color was measured using a Konica Minolta CR-400 colorimeter (Japan). Results were expressed in CIE L*, a*, and b* coordinates:

- L* (lightness: 0 = black, 100 = white)
- a* (- = green, + = red)
- b* (- = blue, + = yellow)

Five measurements were taken per formulation and averaged.

2.6 Moisture Content

Moisture content was determined using an infrared moisture analyzer (Sartorius MA 35, Germany) at 130 °C until constant weight was achieved. Results were expressed as percentage wet basis (% w.b.). Three replicates were performed per formulation.

2.7 Water Activity (aw)

Water activity was measured using a Novasina LabSwift-aw meter (USA). Ground samples were placed in the measurement chamber and equilibrated until stable readings were obtained. Three replicates were conducted per formulation.

2.8 Mechanical Properties

Mechanical properties were analyzed using a Brookfield CT3 Texture Analyzer (USA).

A compression test was performed using a cylindrical probe (35 mm diameter). Test parameters were set as follows:

- Pre-test speed: 1.0 mm/min
- Test speed: 1.0 mm/min
- Post-test speed: 10.0 mm/s
- Compression distance: 5 mm or until fracture

The following parameters were recorded:

- Hardness (N)
- Adhesiveness (mJ)
- Fracturability (N)

Ten replicates were analyzed per formulation.



Figure 1. Texture analyzer, Colorimeter, Water activity a_w , and Moisture analyzer.

3. Results and Discussion

3.1 Effect of Formulation on Mechanical Properties

The formulation ratio significantly influenced hardness ($p < 0.05$), whereas the expansion ratio, brightness (L^*), and moisture content did not differ between S1 and S2 ($p > 0.05$). S1 exhibited significantly higher hardness (28.32 N) compared to S2 (18.48 N). The higher hardness in S1 may be attributed to the greater proportion of rice flour, which enhances structural rigidity by increasing starch matrix formation during puffing. Similar observations were reported by Zhang and Hosney (1998), who noted that starch structure and composition significantly influence expansion and mechanical resistance in puffed cereal products. Although S2 demonstrated a slightly higher expansion ratio (3.96), the difference was not statistically

significant. This suggests that, within the tested formulation range, expansion was primarily governed by moisture-induced vapor pressure rather than compositional variation, consistent with the findings of Murugesan and Bhattacharya (1986).

3.2 Moisture Content and Water Activity

Both formulations showed low moisture content (~3.4%) and a_w values between 0.243–0.268, which fall within the safe range for dry snack products ($a_w < 0.6$). Low water activity limits microbial growth and enhances shelf stability (AOAC, 1990). Although S1 showed slightly lower a_w values, the difference was not statistically significant. Therefore, the claim of improved shelf life should be interpreted cautiously and requires further microbial shelf-life testing for confirmation. The results from the development and performance testing of a semi-automatic dual-head puffed rice machine, which involved two key phases: testing the drying and puffing process under various conditions and evaluating the final product quality. Initial experiments conducted on July 19 and July 26, 2025, confirmed the machine's ability to reach target temperatures (up to 240°C) and successfully puff rice using Formula 1 (75g rice: 25g rice bran starch: 2% oil at 220°C for 45s) and Formula 2 (higher oil content at 240°C for 60s). A subsequent test on August 10, 2025, using Formula 3 (70g broken rice: 30g rice flour: 4% oil at 240°C) identified the optimal pressing time as around 60s, noting that deviation caused poor expansion or overbrowning. Further testing on August 23, 2025, comparing different sticky rice preparation methods, found that Formula 4.1 (soaked sticky rice, one round) was successful, while formulas with excessive water (4.2 and 4.3) resulted in soggy products. Finally, the test on September 7, 2025, comparing two sticky rice/Pathum Thani rice bran starch ratios, S1 (40:60) and S2 (50:50 at 220°C for 75s), indicated that Formula S1 yielded the more desirable puffing characteristics, including dryness and structural integrity.

3.3 Quality Evaluation of Puffed Rice Products

On September 11, 2025, puffed rice samples from formulas S1 and S2 were evaluated for physical and textural properties using a texture analyzer (TA) on five replicates each. The analyses included color (L , a , b^*), post-drying weight, moisture content, water activity (a_w), hardness, adhesiveness, and fracturability. Formula S1 showed slightly higher brightness (L^*) values and marginally higher moisture content (3.43–3.48%) compared to S2, with water activity ranging from 0.243–0.268 for S1 and 0.243–0.255 for S2. Both formulas had similar expansion ratios (3.87 for S1 and 3.96 for S2), indicating no significant difference. Regarding textural properties, S1 exhibited significantly greater hardness (average 28.32 N, peaking at 52.21 N), while S2 had a lower average hardness (18.48 N) with some samples reaching 31.70 N. No adhesiveness was observed in S1, whereas minor adhesiveness appeared in some S2 samples, especially samples 6 and 10. Fracturability was more pronounced in S2 samples, while S1 generally showed negligible or zero fracturability.

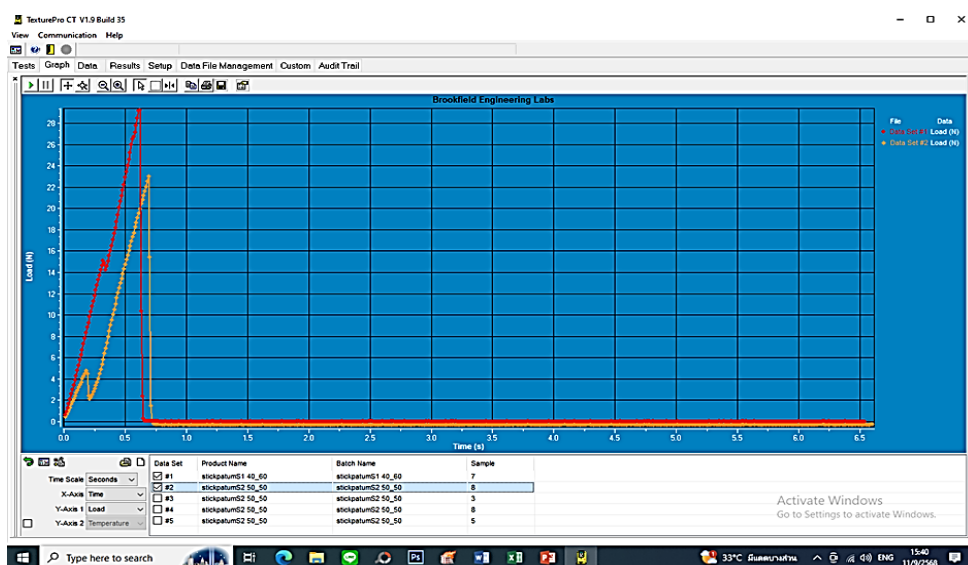


Figure 2. Texture Analyzer Results

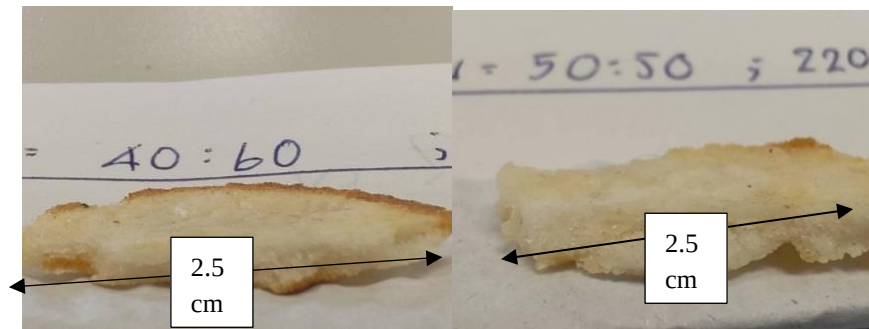


Figure 3. Close-up photographs of the puffed rice sheets were taken.

Table 1. Summary of Comparative Analysis

Test Parameter	S1 (40:60)	S2 (50:50)	Statistical Result (t-test)	Conclusion
Hardness (N)	28.52 ± 1.18^a	20.49 ± 0.902^b	Significant difference ($p < 0.05$)	S1 is significantly harder than S2
Expansion Ratio	3.85 ± 0.07^a	3.93 ± 0.06^a	No significant difference ($p > 0.05$)	Both formulas have similar expansion ratios
Brightness (L^*)	73.87 ± 1.43^a	72.79 ± 1.99^a	No significant difference ($p > 0.05$)	Color brightness is not significantly different
Moisture (%)	$3.52\% \pm 0.44^a$	$3.51\% \pm 0.25^a$	No significant difference ($p > 0.05$)	Moisture levels are comparable

The results indicate that the formulation ratio significantly influenced the mechanical properties, particularly hardness. Formula S1 (40:60) exhibited significantly higher hardness (28.52 ± 1.18 N) compared to S2 (20.49 ± 0.902 N) ($p < 0.05$). This suggests that increasing the proportion of Pathum Thani rice flour improved the structural rigidity and compression resistance, resulting in a firmer puffed rice sheet. The relatively low standard deviation values also indicate good consistency within each formulation. In contrast, no significant differences were observed in expansion ratio, brightness (L^*), or moisture content between formulations ($p > 0.05$). The expansion ratios were comparable (3.85 ± 0.07 for S1 and 3.93 ± 0.06 for S2), indicating that both formulations achieved similar puffing efficiency under the same processing conditions. The small standard deviations reflect uniform expansion behavior. Similarly, brightness values were statistically similar (73.87 ± 1.43 for S1 and 72.79 ± 1.99 for S2), suggesting that formulation ratio did not markedly influence surface color development during puffing. Moisture contents were nearly identical ($3.52 \pm 0.44\%$ for S1 and $3.51 \pm 0.25\%$ for S2), confirming that drying and moisture distribution were consistent across treatments. Overall, these findings demonstrate that while formulation ratio strongly affects textural strength (hardness), it does not significantly alter expansion performance, color brightness, or final moisture level under the selected processing conditions. This indicates that texture can be tailored through formulation adjustment without compromising key physicochemical characteristics.

4. Conclusion

This study evaluated the performance of a semi-automatic dual-head puffing machine and investigated the effects of formulation ratio on the physicochemical and mechanical properties of sheet-type puffed rice. The results demonstrated that formulation ratio significantly influenced mechanical properties, particularly hardness ($p < 0.05$). Formula S1 (40:60, glutinous rice: Pathum Thani rice flour) produced significantly higher hardness values compared to S2 (50:50), indicating greater structural strength and resistance to breakage. In contrast, S2 yielded a softer product with higher variability in fracturability and slight adhesiveness in some samples. No significant differences were observed in expansion ratio, brightness (L^*), or moisture content between formulations ($p > 0.05$). Both formulations exhibited low moisture content and water activity (<0.3),

typical of dry expanded snack products. The dual-head puffing system operated effectively under the selected processing conditions (220 °C for 75 s), producing uniform sheet-type puffed rice. The findings provide quantitative evidence that the formulation ratio plays a critical role in determining textural properties and can be adjusted to achieve desired product characteristics.

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