Research Article

The Optimization of Extrusion Parameters and Rice Flour Blends in Ready-to-Eat Extruded Thai Rice Snacks

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Abstract
The ready-to-eat snack products from traditional Thai's rice flour (Khao bahn nah 432: KB432) and corn grits were developed using a single screw extruder. In this study, the ratio between rice flour and corn grits was measured at three different levels (50:50, 60:40 and 70:30). On the viscosity profile of mixed flour, one hundred percent of rice flour formed gel and showed the highest viscosity, while increasing the amount of corn grits resulted in decreased viscosity. In the heat-cool cycle, the final viscosity of 100% rice flour was the highest and that of 50% rice flour showed the lowest. For extrusion parameters, the die temperatures were varied at 150, 160 and 170 °C. The results showed that an increasing amount of rice flour and die temperature caused a decrease in the texture's puffiness, density and expansion rate, while the redness (a*) color of the product was increased. Response surface methodology (RSM) was used to optimize the extrusion conditions of snack production. The result indicated that the optimum ratio between rice flour: corn grits was 50:50, the optimal temperature at the die section was 150 °C to produce the ready-to-eat extruded Thai rice snack, a new alternative snack product from rice flour.

Keywords: Expansion rate, Khao bahn nah432, Puffiness, Rice snack, Single screw extrusion

1 Introduction

In 2023, the total value of the snack market in Thailand was 46,500 million baht and growing by 5.4% a year for the next four years to 57,300 million baht in 2027 [1]. In general, snack products often contain flour derived from grains such as wheat, rye, and barley, which are common causes of allergic reactions in humans due to gluten intolerance [2]. Approximately 1% of the global population is affected by celiac disease, an autoimmune disorder that causes significant intestinal damage [2], [3]. To reduce the risk of celiac disease, many people choose to avoid consuming products that contain flours associated with gluten intolerance [2]. Therefore, rice flour presents a valuable opportunity to replace wheat flour in food products. It is considered as a gluten-free alternative and when used in snack products, helps ensure that consumers are not exposed to the risk of celiac disease [4], [5]. Park *et al*., reported that there are many studies on the use of rice-based flour in bread and bakery products, pasta noodle products, beer, etc. Moreover, many studies have explored the use of rice-based flour with different ingredients and processing methods, such as baking, baking combined with enzyme hydrolysis and extrusion technology [4], [5].

Extrusion technology has been a useful tool for use in food processing or food ingredients. The typical extruded process consists of mixing, shearing, forming, texturising, and cooking of raw material into a food product [6], [7]. Several products could be obtained from extrusion technology, such as breakfast cereals, snacks, pasta, macaroni, spaghetti, textured soy protein, meat analogs, and animal feeds [8], [9]. Snack products produced by the extrusion process are one of the fastest-growing food [5], [10] and it is noted that their food shapes, structures could be different depending on the processing conditions [9]. There are many studies from 2023 to 2025 focusing on extrusion technology, particularly in relation to optimization and prediction in food application; Kebede ali *et al*., studied the teff-based puffed/extruded product blended with chickpea flour, examining the effects of extrusion process parameter on product quality [11], Teferi *et al*., investigated the ratio of local raw materials (cowpea: emmer wheat) using twin-screw extruder and analyzed the effects of extrusion conditions on nutritional properties of products [12], Umoh *et al*., examined the effects of soybean and aerial yam flour blends, as well as extrusion parameters on sensory properties and the process optimization [13]. Since extrusion technology consists of multiple operating units and involves many parameters that need to be precisely controlled, careful study and verification are necessary. Even slight differences in parameters can significantly affect production and the final product.

In Thailand, the chance of local rice for the food industry has been promoted as several studies, Suklaew *et al*., investigated the physicochemical and functional characteristics of RD43 rice flour, including pasting properties, hydration capacity, and amylose content, and discussed its applications in food formulations [14], Chooklin *et al*., optimized extrusion conditions (germinated Med Fai brown rice flour), using twin-screw extrusion to develop healthy snacks. They modeled screw speed, die temperature, and rice flour content effects on expansion, texture, GABA content, and nutritional quality via Response Surface Methodology [15]. Wrivutthikorn developed crispy roti using riceberry rice flour to replace all-purpose wheat flour, evaluating the texture and sensory quality of the resulting product [16]. Musika *et al*., produced gluten-free pasta using Riceberry rice flour supplemented with cricket powder via twin-screw extrusion. They used D-optimal mixture design to optimize blend proportions, achieving statistically significant predictive models ($R^2 \geq 0.75$) [17]. Khao bahn nah 432 rice is a variety of rice widely grown in the eastern and northeastern regions, typically cultivated in flooded fields. It has 28.0% amylose, medium gel consistency (48 mm) and medium gelatinization temperature [18]. The elongation ratio of cooked rice was 1.66 times. The cooked rice has an off-white color, slightly glossy and the texture is soft. The adhesion was not sticky-not crumbly [18], [19]. It is suitable for rice processing, especially for making Chinese noodles and rice vermicelli. The noodles are stickier and softer than other noodle products on the market [20]. Diversifying and adding value to local rice by processing it into flour for use as a mixed ingredient in modern food is important. Therefore, the utilization of local rice varieties in food products using extrusion technology should be investigated. Chuechomsuk *et al*., [5] studied the development of gluten-free snacks from different rice flours by extrusion. The result found that producing gluten-free snacks from jasmine rice: brown glutinous rice: brown riceberry at ratio 1:1:1 with nutritionally rich protein, dietary fiber and antioxidants.

This research aims to develop KB432 rice flour into a snack product suitable for consumers. It uses gluten-free rice flour as the main raw material, combined with corn grit (varying ratio), to study the effects of extrusion parameters, particularly die temperature, on the quality of the extruded product through an optimization process.

2 Methodology

2.1 *Materials*

The Khao bahn nah 432 (KB432) cultivar of Thai rice (*Oryza sativa*) was obtained from the rice mill of Suan Dusit Rajabhat, Rice mill factory, Co Ltd. (Prachinburi, Thailand). The rice was stored in vacuum LDPE plastic bags in the fridge (4–8 °C). Corn grits were obtained from Thai flour mill industry, Co Ltd. (Samut prakan, Thailand), Medium-coarse G2 grade, corn size 300–1000 micron, moisture content 11–14% and corn starch >70%.

2.2 *Determination of the chemical composition of rice*

Protein (%Nx5.95), fat, fiber, ash, carbohydrate, and moisture content of the rice were analyzed [21]. Then the rice was cleaned and the rice ground into flour with a fine grinder (GM-D, Bauermeister, USA). The flour was sifted with a sieve at 80 mesh and packed in an aluminum foil pouch. It was stored at 4 °C for further study.

2.3 *Determination of the viscosity behavior of mixed flour*

The pasting properties of mixed flour were measured using Rapid Visco Analyzer (RVA-4, Perten Instrument, Sweden) according to the AACC 61-02.01 method (11th Edition). To measure the paste viscosity of mixed flour, 3 grams of flour and 25 mL of water were mixed in a canister and then subjected to a heat-hold-cool-hold temperature cycle that mimics cooking processing. The paste viscosity parameters are expressed in rapid viscosity unit (RVU). The viscosity, maximum (peak) viscosity, minimum viscosity (holding strength), final viscosity, and setback were recorded.

2.4 *Formulation and the single screw extruder operation*

The single screw extruder (SE-D28L20 WCL, 2016) apparatus is shown in Figure 1. The operation conditions consist of two parts; the first part was fixed parameters as Table 1 and the second part, the parameters of flour ratio and die temperature were varied as shown in Table 2.

Three blending ratios (rice flour:corn grits) were used as 50:50, 60:40 and 70:30. The extrusion was carried out using a single screw extruder with a 3.0 mm diameter. Under feeding zone, the mixing ingredients consist of mixed flour 92–95%, calcium carbonate salt 1.0%, soybean oil 1.0% and a calculated amount of water was added to the mix ingredients (moisture content ≤15% wb). The extrusion conditions were set following Table 1–2, with the single screw speed controlled at 150 rpm. Extrudates were collected, cooled down to room temperature and then dried at 60 °C for 15 min in a tray dryer. The extrudates were kept in polypropylene bags until further studies.

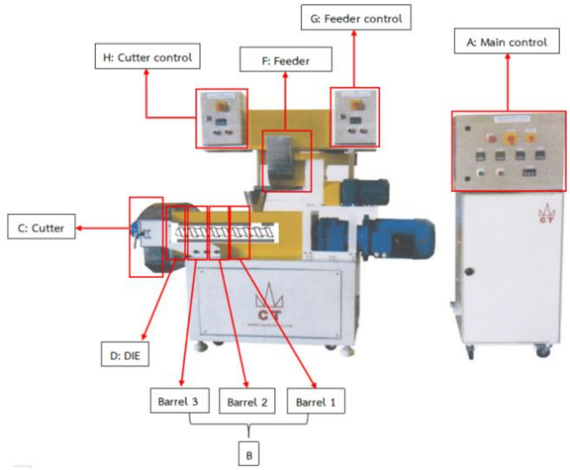

Figure 1: Single screw extruder apparatus.
**Single Screw Extruder (SE-D28L20 WCL, 2016) handbook*

Table 1: The operation control of the single screw extruder parameters.

Parameters	Conditions
Barrel 1 (°C)	100 ± 5
Barrel 2 (°C)	130 ± 5
Barrel 3 (°C)	130 ± 5
Cutter (rpm)	150 ± 2
Feeder (rpm)	5 ± 2

Table 2: Ratio of raw materials and die temperature.

Treatment	Rice Flour: Corn Grits	Die Temperature (±5 °C)
1	50:50	150
2	60:40	150
3	70:30	150
4	50:50	160
5	60:40	160
6	70:30	160
7	50:50	170
8	60:40	170
9	70:30	170

2.5 *Determination of snack products*

2.5.1 *Physical properties*

Color was measured using a Hunter Lab colorimeter (Color Flex 45/0, Color global, USA). Color parameters were L* a* and b* values with five replicates [20].

Bulk density was measured by the sesame replacement method, which was modified from a method using canola seed [22]. Samples were placed in a particular volume container and then sesame was poured over the sample. Then, both sesame and sample were poured out. The sesame weight was recorded and the bulk density of the product was calculated as the weight of the snack to their unit volume (g/cm^3).

The expansion rate was calculated as the mean diameter of the product (mm) divided by the diameter of the die hole (DIE, mm). The measurement was replicated ten times, and average values were calculated [23].

The texture characteristics were measured at the product's exact size using a Texture analyzer (TA.XT plus, Stable Macro, England) employing a single compression method with a spherical probe P/100 at the speed of 1.0 mm/s until reaching 70% deformation and a post speed of 10.0 mm/s. Hardness and crispness were recorded in newtons of force. The measurement was replicated ten times for each treatment [24].

2.5.2 Chemical properties

Water activity was measured using an AQUA LAB meter (CX3TE, England). The sample was ground and placed into two-thirds of the cassette. The measurement was done in triplicate.

Moisture content was determined by heating samples in an aluminum moisture analyzer cup for 2 h or until the weight was stable. A 2–3 g sample was poured into a cup, then placed it in a hot air oven at 105 °C for 5–6 h with the aluminum lid open. The sample was then allowed to cool in the desiccator to room temperature. Then, the samples were weighed and heated for another 30 min, the weight was recorded again and the moisture content was calculated [25].

2.5.3 Sensory properties

Sensory tests were conducted by 72 untrained panelists (each panelist tasted four samples, with each sample replicated 32 times) with a 9-point hedonic scale (1-extremely dislike to 9-extremely like). Untrained panelists received approximately 3 pieces of each sample in a randomized order labeled with a three-digit code [26]. The untrained panelists were asked to evaluate their preferences, based on attributes including color, appearance, crispiness, flavor and overall liking.

2.6 *Statistical analysis*

All data were performed and presented as mean±standard deviation. The statistical analysis used was analysis of variance (ANOVA). The average difference of samples was compared by DMRT (Duncan's new multiple range tests). A probability value less than 0.05 was considered significant. The correlation between the response variable and the independent variable was used to fit the coefficient of the quadratic polynomial model. The quality of the model fit was measured using analysis of variance. The optimization was done in the feasible region via the contour graphs of the response variable [26].

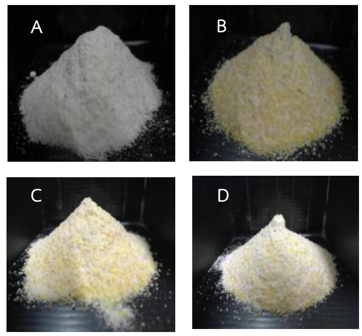

Figure 2: Different ratios of rice flour: A: rice flour 100%, B: rice flour:corn grits 50:50, C: rice flour:corn grits 60:40, D: rice flour:corn grits 70:30.

3 Results and Discussion

3.1 *Physical and chemical properties of mixed flour*

The ratio between KB432 rice flour and corn grits in three formulas was compared with 100% KB432 rice flour. The appearance of mixed flour was shown in Figure 2.

The physical and chemical properties of 100% rice flour and rice flour: corn grits mixed were analyzed. 100% rice flour showed 12.23% of moisture, while mixed flour had a range of moisture between 11.57–11.80. For a_w value, all treatments had a_w in the range between 0.60–0.62. For color values, 100% rice flour showed the highest lightness and tended to decrease when more corn grits were added. For redness and yellowness color, 100% rice flour showed the lowest value, and there was a tendency to increase when adding more corn grits.

3.1.1 Viscosity properties

The pasting profiles of mixed flour are given in Figure 3. The results of viscosity behavior at different temperatures and times were as follows: 100% rice flour had gelatinized at 3.67 min; the highest viscosity was 181.28 RVU at 5.8 min; and the lowest viscosity was 162.12 RVU at 7.67 min. Then the flour had retrogradation and a final viscosity of 350.56 RVU after the cooling stage. When heated, rice flour and rice flour mixed with corn grits, 100% rice flour absorbed water and puffed more than rice flour mixed with corn grits (rice flour 50%, 60% and 70% respectively). At the paste temperature; 100% rice flour formed a gel and attained the highest viscosity, and increasing the amount of corn grits resulted in decreased viscosity. The final viscosity of 100% rice flour was the highest, and that of 50% rice flour the lowest; this may be due to the increased ratio of corn grits. The 100% rice flour also had the highest retrogradation viscosity, while rice flour mixed with corn grits presented a lower value than that found in 100% rice flour.

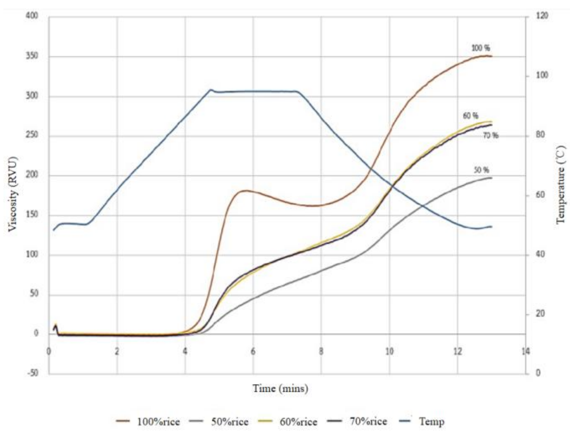

Figure 3: Pasting profiles obtained from different ratios of rice flour: rice flour 100%, rice flour 50%, rice flour 60%, rice flour 70%.

In general, the ratio of amylose to amylopectin in starch varies between different types of grains, and this impacts their texture and cooking properties [27]–[29]. The amylose content of rice flour ranged from 17–23% and amylopectin ranged from 70–85% [29], [30], which corn starch also has high amylopectin (72-75%) [31]. While the starch tends to have different characteristics compared to rice. Corn starch is more granular and gives a firmer texture when cooked [32], whereas rice starch has lower amylose content, resulting in a more sticky and soft texture [29]–[31].

The experiment plan included modifying and substituting rice flour in the snack formula, forming snacks under varying extrusion conditions and testing under three different rice flour ratios. The resulting extrudate or product sample had different puffing characteristics, as shown the appearance in Figure 4. The appearance of the snack was shown symmetrical round shape until shapeless. Snack weight was inconsistent in the range between 0.4–1.1 grams, depending on the expansion capacity. The product had a creamy white color that was characteristic of mixed flour from rice and corn.

a) b) c)

Figure 4: Product prototype; appearance of snack in different flour ratios at 150 °C die temperature; a) 50:50, b) 60:40 and c) 70:30.

Under the ratio of mixed flour and die temperature conditions, the results are shown as follows; at 150 °C die temperature and 50:50 mixed flour, the higher amylopectin content from both rice and corn leads to a softer and more puffing texture, while the presence of more amylose (especially from corn) showed the snack a bit more crispiness (Table 3). When increasing rice:corn to 70:30, the rice starch has a higher proportion of amylopectin. Therefore, the snack was denser compared to a 50:50 mixed flour; the chewiness of the mixed flour 70:30 was slightly more pronounced than the 50:50 mixed.

3.2 *Physical properties of snacks*

The physical properties of all treatments consisted of density, expansion rate, texture and color value. They are shown in Tables 3 and 4, respectively. The density of snack products (Table 3) showed that under the same flour ratio 50:50, the high temperature treatment (170 °C) had lower densities than the lower temperature treatments (150 °C). There was a relationship between the die temperature and flour ratio, which showed that an increased ratio of rice flour might lead to decreased bulk density. This may be caused by adding water to barrel 1 via the feeder; it was easier for a screw to move material to the different parts of the machine when the mixed flour was pushed through the die, producing abnormally high density and out of trend results [33]. The different density values may be due to the expansion of the sample under the varied extrusion conditions [33], [34]. The moisture in the material evaporates according to the die temperature and screw speed transmitted to the material, resulting in an increase in the temperature of the material and different physical characteristics of snack products [25]. When the material was extruded through the die, water in the material rapidly evaporated, producing the expanded and porous structure [6], [9].

Table 3: Bulk density, expansion rate, hardness and crispiness of the snack.

Treatment (Rice Flour: Corn)	Bulk Density (g/cm^3)	Expansion Rate	Texture	
			Hardness (N)	Crispiness (N)
150°C				
1 (50:50)	0.25±0.03^{b}	11.64±1.90^{ab}	34.74±9.38^{c}	207.26±48.59^{ab}
2 (60:40)	0.27±0.01^{a}	13.72±0.71^{a}	40.77±6.29^{bc}	196.90±40.87^{bc}
3 (70:30)	0.23±0.01^{bc}	10.82±0.36^{b}	32.76±7.03^{cd}	192.92±34.98^{bc}
160°C				
4 (50:50)	0.26±0.00^{a}	12.52±0.98^{ab}	59.57±16.08^{a}	226.79±42.40^{ab}
5 (60:40)	0.24±0.02^{b}	12.03±0.91^{ab}	52.40±10.98^{a}	244.12±48.19^{a}
6 (70:30)	0.21±0.02^{c}	9.14±1.11^{c}	34.17±8.21^{c}	186.84±65.11^{bc}
170°C				
7 (50:50)	0.24±0.02^{b}	13.02±0.93^{a}	45.82±8.26^{b}	242.47±77.67^{a}
8 (60:40)	0.22±0.02^{c}	9.62±2.36^{c}	33.96±4.37^{cd}	219.24±25.39^{ab}
9 (70:30)	0.20±0.01^{c}	10.57±0.70^{b}	31.96±12.53^{d}	180.60±91.71^{c}

$^{a, b, c, d}$ means that the different superscript letters in the same columns are significantly different (p<0.05).

For the expansion rate, treatment 2 had the highest and treatment 8 had the lowest. The inflatable product has a diameter larger than the die hole (3 mm); the speed of the screw may affect the pressure in the machine. As the pressure increases, the material can be pushed out more easily. The heat of the die and the initial humidity of the material affect water evaporation from the material. Koksel and Masatchioglu [35] reported that the puffiness of the product increases as the screw speed increases, because as the screw speed increases, the pressure in the material increases. When the product was pushed through the die, the water in the product quickly evaporated, giving a dry and puffed product. Considering the ratio between rice flour and corn grits, the viscosity behavior curve showed that at the same die temperature, a low rice flour ratio had a lower gelatinization temperature than a high rice flour ratio [9], [32]. The 50:50 ratio of rice flour and corn grits cooked faster than the 70:30 ratio; the expansion rate was highest and tended to decrease with increased rice flour. Variation in the expansion rate affects the shape and size of rice snacks because rice flour has lower starch complexity. Increasing the proportion of rice flour results in less puffing compared to corn starch.

Hardness was highest in treatment 4 and lowest in treatment 9, due to the initial moisture of different materials. High humidity had a higher hardness than low humidity. It was consistent with Zhuang *et al.,* [36] who studied how production conditions of Indica rice extrusion affected the physicochemical properties of snacks from Indica rice. Zhuang *et al.,* reported that increased moisture content of the material will also increase the hardness of the product [36]. For the crispiness, treatment 5 had the highest, and treatment 9 had the lowest. When the material passes through the die, the crispiness occurs as the sample breaking apart with noise. The structure of extruded products was porous, puffed, and crispy because, as the material enters the extrusion process, water molecules in the starch granules were heated and converted to vapor, which disperses into the atmosphere.

Table 4: Color of snack product using extrusion.

Treatment (Rice Flour: Corn)	Color		
	L*	***a****	***b****
150 °C			
1 (50:50)	79.96±0.97^{bc}	3.56±0.26^{c}	28.22±0.30^{b}
2 (60:40)	76.64±0.14^{e}	4.72±0.09^{a}	26.66±0.36^{c}
3 (70:30)	77.38±0.22^{e}	4.78±0.07^{a}	26.81±0.64^{c}
160 °C			
4 (50:50)	79.07±0.83^{cd}	4.23±0.32^{bc}	31.82±1.01^{a}
5 (60:40)	80.49±0.36^{ab}	3.80±0.18^{cd}	28.46±0.18^{b}
6 (70:30)	79.26±1.04^{cd}	3.57±0.62^{c}	26.50±0.29^{c}
170 °C			
7 (50:50)	81.49±0.41^{a}	2.25±0.48^{e}	26.58±0.60^{c}
8 (60:40)	78.61±0.37^{d}	3.24±0.12^{cd}	27.63±1.34^{bc}
9 (70:30)	79.32±0.40^{cd}	2.89±0.17^{d}	26.90±0.57^{c}

$^{a, b, c, d}$ means that the different superscript letters in the same columns are significantly different (p<0.05).

Color of snacks, as shown in Table 4, Lightness (L*) was highest in treatment 7 and lowest in treatment 2. Using 70% KB432 rice flour with 30% corn grits resulted in a higher lightness than other ingredients. Moreover, treatment 2, which contains 50% KB432 rice flour and 50% corn grits, resulted in lower lightness than other treatments. Therefore, different degrees of lightness were caused by different ratios of materials, barrel temperature, and die temperature.

For redness (a*), treatment 3 showed the highest value and treatment 7 exhibited the lowest value. For yellowness (b*), treatment 4 had the highest value and treatment 6 exhibited the lowest. The difference in yellowness was due to the amount of corn grits in different materials. Although corn grits were yellow when the amount of corn grits was reduced and rice flour was substituted, this may be because different amounts of materials, barrel temperature and die temperature cause a non-enzyme browning by Maillard reaction, resulting in a different color of the samples [25], [37].

3.3 Chemical properties of snacks

The chemical properties of snack products were shown in Table 5. Water activity (a_w) in treatment 4 was the highest value and treatment 3 was the lowest value. The experimental results were similar to the research of Walai *et al.*, On the development of a breakfast product from banana flour using extrusion technology. In their research, the product had water activity (a_w) in the range of 0.40–0.49 in accordance with the standard and was classified as a difficult food to spoil [38].

Table 5: Chemical properties of snack products using extrusion.

Treatment (Rice flour: Corn)	Water Activity (a_w)	Moisture (%)
150 °C		
1 (50:50)	0.47±0.08^{a}	3.76±0.30^{b}
2 (60:40)	0.39±0.02^{b}	3.23±0.13^{b}
3 (70:30)	0.33±0.01^{c}	3.43±0.12^{b}
160 °C		
4 (50:50)	0.50±0.01^{a}	3.70±0.30^{b}
5 (60:40)	0.40±0.00^{b}	3.62±0.37^{b}
6 (70:30)	0.37±0.01^{c}	4.78±0.40^{a}
170 °C		
7 (50:50)	0.41±0.01^{b}	3.96±0.22^{b}
8 (60:40)	0.46±0.00^{a}	3.16±0.14^{b}
9 (70:30)	0.41±0.00^{b}	3.97±0.17^{b}

$^{a, b, c, d}$ means that the different superscript letters in the same columns are significantly different (p<0.05).

Treatment 6 had the highest moisture content and other treatments had moisture content below<4%. The moisture of the puffed snack was removed through a heating and pressure process, rapidly evaporating the water in the food at the extruder die. Commercial puffed snacks, according to the Ministry of Industry, Thailand No. 1534-2541 Cereal snack. The product standards should have a moisture content of not more than 4%. Experimental results showed that all treatments except treatment 6, moisture content did not exceed the standard.

3.4 *Sensory properties of snacks*

The preference test of the snack products, the participants who sampled variations of the product preferred, the color of treatments 1, 4, and 2, the appearance of treatments 1, 6, and 5, the crispness of treatments 1, 2, and 9, and the flavor of treatments 9, 2, and 1, respectively. In addition, panelists rated the overall acceptance of treatments 1, 2, and 9, respectively, as shown in Table 6. When comparing the experimental results with the preference test, it was found that treatment 1 had the highest scores for color, appearance, crispness, and overall liking, except for the flavor attribute. Therefore, the optimal ratio of rice flour to corn grits was 50:50, with an optimal die temperature of 150 °C for producing the ready-to-eat extruded Thai rice snack.

Table 6: Sensory properties of snack product using extrusion.

Treatment (Rice flour: Corn)	Color	Appearance	Crispiness	Flavor	Overall Liking
150 °C					
1 (50:50)	6.75±1.05^{a}	6.50±1.27^{a}	6.34±1.81^{a}	5.97±1.68^{bc}	6.53±1.57^{a}
2 (60:40)	6.25±1.30^{ab}	6.09±1.79^{ab}	6.16±1.92^{a}	6.03±1.60^{ab}	6.25±1.83^{ab}
3 (70:30)	5.78±1.43^{b}	5.69±1.42^{ab}	5.69±1.40^{ab}	5.75±1.24^{abc}	6.06±1.16^{abc}
160 °C					
4 (50:50)	6.30±1.03^{ab}	6.00±1.39^{ab}	4.74±1.89^{b}	4.93±1.54^{b}	5.37±1.39^{bcd}
5 (60:40)	6.17±1.40^{ab}	6.14±1.66^{ab}	5.44±2.13^{ab}	5.28±1.88^{bc}	5.33±1.82^{cd}
6 (70:30)	6.22±1.21^{ab}	6.19±1.28^{ab}	5.97±1.73^{ab}	5.47±1.90^{abc}	6.06±1.61^{abc}
170 °C					
7 (50:50)	5.91±1.36^{b}	5.42±1.30^{b}	4.64±1.85^{b}	4.94±1.66^{b}	5.03±1.49^{d}
8 (60:40)	5.75±1.55^{b}	5.53±1.70^{b}	5.75±1.67^{ab}	5.25±1.93^{bc}	5.53±1.90^{bcd}
9 (70:30)	5.59±1.50^{b}	5.69±1.66^{ab}	6.16±1.65^{a}	6.25±1.41^{a}	6.25±1.44^{ab}

$^{a, b, c, d}$ means that the different superscript letters in the same columns are significantly different (p<0.05).

3.5 *The optimization of mixed flour: die temperature*

The physical and sensory properties were statistically analyzed to determine appropriate variables to create the overlapping area, and appropriate properties were selected from high R^2 and compared with feasibility. In Table 7, a quadratic model was used to generate the regression equation for predicting the response (Y) in terms of physical and sensory attributes. Crispiness (sensory) showed the highest R^2 value (>0.9), indicating strong predictive ability, while the other responses had lower R^2 values (<0.9), suggesting weaker predictive accuracy.

Based on the quadratic model of physical response, crispiness and expansion ratio showed the highest $R^{2,}$ with the rice flour: corn grit ratio having a greater influence than die temperature. Comparing results with similar research, snacks from brown jasmine rice (JR) showed high hardness and crispiness, which were related to the high amount of total dietary fiber in the raw material. The regression equation also showed R^2 greater than 0.9 [5].

Table 7: Statistical analysis of physical and sensory properties of snack product.

Response Properties (Y)	R^2	Regression
Physical		
Bulk density	0.777	$y = 12.074-0.134x_1 + 0.023x_2 +0.000x_1x_1 +0.000x_2x_2+0.000x_1x_2$
Expansion rate	0.867	$y = -225.526+2.860x_1+0.494x_2 +0.010x_1x_1 +0.008x_2x_2+0.003x_1x_2$
Hardness	0.675	$y = -1194.720+11.5208x_1+12.235x_2 -0.036x_1x_1 +0.088x_2x_2+0.010x_1x_2$
Crispiness	0.848	$y = -17880.200+195.674x_1+84.336x_2 +0.599x_1x_1 +0.613x_2x_2+0.064x_1x_2$
Sensory		
Color	0.789	$y = 25.750-0.164x_1-0.147x_2 +0.000x_1x_1 -0.001x_2x_2+0.002x_1x_2$
Appearance	0.874	$y = 12.932-0.010x_1-0.219x_2 +0.001x_1x_1 +0.002x_2x_2+0.003x_1x_2$
Crispiness	0.948	$y = 55.393-0.193x_1-1.214x_2 -0.000x_1x_1 +0.003x_2x_2+0.05x_1x_2$
Flavor	0.869	$y = -58.209-0.324x_1-0.942x_2 +0.000x_1x_1 +0.003x_2x_2+0.004x_1x_2$
Overall acceptance	0.847	$y = 113.043-1.008x_1-0.919x_2 +0.003x_1x_1 +0.004x_2x_2+0.003x_1x_2$

The appropriate properties of snack products were plotted to create a contour diagram between the physical (bulk density, expansion rate, and hardness) and the sensory (crispiness and overall acceptance) properties to find the overlapping areas, as shown in Figure 4.

Figure 4 shows the overlapping area between physical and sensory properties: bulk density range of 0.2–0.4, expansion rate range of 10.0–15.0, hardness range of 30–50, crispiness range of 5.5–9.0, and the overall acceptance range of 5.5–9.0, respectively. Therefore, multiple overlapping areas were obtained, and appropriate points were selected in the possible areas, resulting in a 50:50 ratio of rice flour: corn grid and die temperature of 150 °C, which produced the final product.

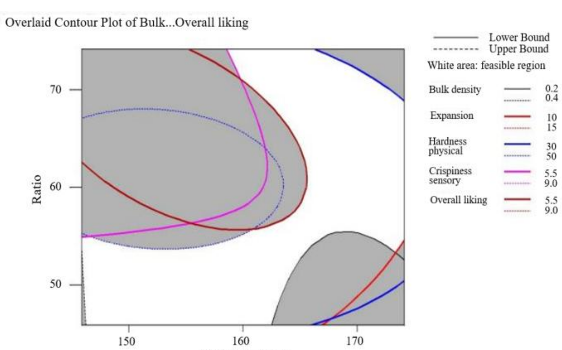

Figure 4: Overlapping area between physical and sensory properties.

4 Conclusions

Development and production of snacks from Khao Ban Nah 432 rice flour and corn grits using single screw extrusion. The optimum material and conditions were the ratio of rice flour: corn grits at 50:50 and die temperature at 150 °C, which affects the shape, puffiness, bulk density, expansion rate, and texture. An increase in rice flour and a higher die temperature resulted in a decrease in puffiness, bulk density, and expansion rate. Therefore, there is a potential in the food processing industry to use Thai rice flour, either in fulfill form or as a replacement in the product.

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Author Contributions

R.C.: conceptualization, investigation, data curation, writing-review and editing; S.R.: formal analysis and editing; R.S.: supervision; S.W.: supervision; S.M.: formal analysis and editing; W.S.: formal analysis and editing. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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