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Original research article

Optimizing Extruded Snack Production from Germinated Med Fai Brown Rice by Using Response Surface Methodology

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ABSTRACT

The aim of this study was to increase the value of Med Fai brown rice through germination and extrusion for production of healthy snacks. The physical and chemical properties of germinated Med Fai brown rice and the optimum extrusion conditions were determined. Med Fai paddy rice was germinated and prepared. The extruded Med Fai brown rice flour was produced using twin-screw extrusion cooking. The effects of process parameters such as germinated rice flour content (2.5-10%), screw speed (400-500 rpm) and die temperature (140-150°C) on extrudate properties were studied. Germination was found to have an influence on the physical and chemical properties of the germinated brown rice flour (GBRF). The Colour value (L* and b*), protein content, fiber content, γ-aminobutyric acid (GABA) content, vitamin B_1 and total phenolic content were increased. The hardness, bulk density (BD) and colour values of the extrudates were all influenced by GBRF. Hardness and BD were increased when GBRF and die temperature were increased, but the expansion ratio (ER) and a* value were decreased. The ER and L* values decreased when the screw speed was reduced, but the a* value increased. 5.38% GBRF, 450.58 rpm screw speed and 144.55°C die temperature were the optimal extrusion parameters for germinated extruded snack. The extruded Thai curry-coated snack (Kang Kua) had the highest overall score of 7.67 (moderate to very good). Thus, the nutritional value of Med Fai brown rice flour was increased by germination. Extrusion conditions affected the properties of extruded Med Fai brown rice flour. Germinated Med Fai brown rice flour is suitable as a functional ingredient in snacks.

Keywords: Extrusion; Extruded snacks; Germination; Med Fai rice; Response surface methodology

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1. Introduction

Snack foods are popular foods that are easy to consume and have appealing flavor and satisfying texture. They also tend to be high in calories and low in nutritional value due to their ingredients, which generally consist of starch flour, fat and sugar, with high sodium content. Snacking excessively can result in health issues such as cardiovascular disease, obesity and malnutrition. As a result, readily available meals should seek to give nutritional content while also being a healthful product. There have been various unsuccessful attempts seeking to make healthy snacks with improved nutritional value while still keeping the sensory attributes of flavor, smell, and texture that appeal to consumers. As it stands, people continue to eat popular yet unhealthy snacks [1].

Rice (*Oryza sativa* L.) was used as a raw material for extruded snack in the extrusion process. Rice is one of the staple foodstuffs in Thailand and Asia. Brown rice is higher in nutritional value than ordinary milled rice grains (for example, dietary fibers, phytic acids, vitamins B and E) and suitable for producing healthy snacks. The bran layers and germ contain all of these chemicals [2].

Because of the present drop in rubber and oil palm prices in Thailand's southern region, the government has implemented a strategy to encourage intercropping within rubber plantations. Farmers in Nakhon Si Thammarat province have boosted their use of upland rice. Med Fai is a non-glutinous, photoperiod-sensitive upland rice variety with a flowering date of March (50% flowering). It has an erect plant type, stands 150 cm in height, has a strong culm, a green-colored leaf and leaf sheath, a 32.21 cm panicle length, mostly compact panicle, 218 healthy seeds per panicle, straw-colored husk, dark purple dehulled grain, slender grain shape, heavy chalkiness, good milling quality, intermediate amylose content (20.9%), moderately soft texture when cooked, and no aroma. Med Fai is distinguished by its rich purple pericarp, excellent quality for cooking and eating, and great nutritional value [3]. Moreover, germinated brown rice (GBR) is considered to be an innovative rice by preserving all the nutrients in the rice grain for consumption to create the highest value from rice. GBR is brown rice that has been soaked in water to induce slight germination, as evidenced by 1-2 mm of root growth. Endosperm is softened and enzymes are activated throughout the process, and nutrients in the brown rice such as protein, dietary fiber, GABA, γ-oryzanol, inositols, tocotrienols, vitamin B_1, magnesium, potassium and zinc are increased while phytic acid is decreased [4]. Due to its high GABA, phenolic compound and fiber content, germinated brown rice flour (GBRF) is a healthy ingredient for use in food. Continuous consumption of GBR can prevent colon cancer, regulate blood sugar level, and prevent heart disease [5]. In addition, it can be used as a raw material in the production of various foods, including germinated brown rice balls, soup, bread, doughnuts, cookies, rice burgers and snacks. Additionally, it was reported that the GABA content of extruded snacks produced from pre-germinated brown rice was unaffected by feed moisture level or screw speed [6, 7].

Due to its great productivity and capability to conduct many operations using just one piece of equipment, extrusion cooking is one of the most popular methods for processing rice and other cereal-based snack foods. Furthermore, the extrusion method is appropriate for the manufacturing of snack products, as the expandable structure generates a crisp texture, high productivity and a varied range of improved and high-quality products [6]. Grain flour is combined and cooked under high temperature and pressure in the barrel section during extrusion cooking. The resulting plasticized mass is extruded via a small hole, such as a die of various forms. The puffed extruded snacks are sliced into various sizes depending on the preference of the consumers. Extrusion of snack foods necessitates the management of several aspects that directly or indirectly influence consumer acceptability in order to produce products that will be chosen by consumers in a highly competitive market. Moisture content of feed, raw material composition and proportion, extrusion temperature and screw speed all influence these quality criteria. As a result, maintaining control over these variables is critical for producing desirable extruded snacks [8]. The Box-Behnken design has been described as a widely accepted response surface methodology (RSM) for finding the best conditions to achieve the desired outcome by optimizing the values of selected variables that influence the outcome [9]. The goal of this study was to see how the quality of germinated Med Fai brown rice and the extrusion conditions (GBRF, screw speed and die temperature) influences the functional qualities of extruded snack from germinated Med Fai brown rice flour.

2. Materials and Methods

2.1 Preparation of germinated brown rice flour (GBRF)

The paddy rice Med Fai (approximately 20.9% amylose) was purchased from Bannongklasamakkee community enterprise, Thungsong Amphur, Nakhon Sri Thammarat province, Thailand. The production of GBR was carried out using a soaking procedure that was slightly modified from Chalermchaiwat et al. [7]. The rice was steeped in tap water, which was changed every day for 4 days at room temperature, until it measured 0.5-1 mm long. Following germination, the GBR was dried for 5.5 h at 55°C in a hot-air dryer to obtain a moisture level of 9-12%. It was then milled into flour in a grinder and passed through a 250 µm (60 mesh) screen.

2.2 Extrusion and processing conditions

A mixer was used to fully combine GBRF (2.5-10% w/w), Sungyod flour (7.5-30% w/w), corn grit (46% w/w), palm oil (3% w/w), water (7% w/w), sugar (5% w/w), and calcium carbonate (1% w/w) for 10 min. Before extrusion, the mixture was wrapped in aluminium foil bags and held at 25°C. The extruder was a co-rotating twin-screw extruder with a barrel with six sections, a die plate, and one circular die hole (3 mm diameter). The barrel length-to-diameter ratio (L/D) of the extruder was 870:25. A feeder was used to feed the mixture into the extruder. The barrel temperature profile was 40°C (section 1), 95°C (section 2), 120°C (section 3), 130°C (section 4), 130°C (section 5), 120°C (section 6), and 140-150°C (at the die plate). The speed was between 400-500 rpm. The extruder had a torque indicator that displayed the percent of torque in relation to the current draw by the drive motor. A single-screw feeder was used to feed raw materials into the extruder. The feed rate was set at 30 rpm. The feed had a moisture level of 12%w/w. The extrudates were cut at 75 rpm using a speed die face cutter with four bladed knives. The extrudates were collected after extrusion, dried for 10 min in a forced-air oven at 80°C, vacuum wrapped in aluminium foil bags, and stored at 25°C until further use.

2.3 Experimental design

The impact of extrusion conditions on responses were investigated using RSM. The RSM method was used to create various combinations for experimentation [10]. Three factors on three levels were employed in a Box–Behnken experimental design. The germinated rice flour concentration (2.5-10%), screw speed (400-500 rpm), and die temperature (140-150°C) were all independent factors in this study. Expansion ratio, hardness, bulk density, and color (L*, a* and b*) were the response variables. Table 1 shows how the independent variables are presented in terms of coded values, -1, 0, and 1. There were 17 runs in total, each containing three replicates of the center point and three blocks. The order of the experiments had been fully randomized. A quadratic model was used to establish the experimental data.

Table 1. The independent variables are presented in terms of coded values.

Variables	Code		
	-1	0	1
A	2.5:7.5:30	5:15:20	10:30:00
B	400	450	500
C	140	145	150

Remark: A: Blend ratio (Germinated Med Fai flour: Sung yod flour: Rice flour), B: Screw speed (rpm), C: Die heat temperature (°C).

2.4 Properties of extrudates

2.4.1 Expansion ratio

The diameter of the extrudate was measured with a vernier caliper (ten randomly chosen pieces of extrudate from each test run) and the sectional expansion was calculated as the ratio of the diameter of the extrudate to the die hole [5].

$$Expansion\ ratio\ =\ \frac{Diameter\ of\ extrudate}{Diameter\ of\ die\ hole}.$$

2.4.2 Texture hardness

A texture analyzer was used to determine the hardness of the extrudates. They were measured with a TA-XT plus Texture Analyzer using a 36 mm cylinder probe. A 5 mm/sec pre-test speed, 5 mm/sec test speed, 10 mm/sec post-test speed and compression of 50% strain were used to compress individual pieces of sample until they broke [7]. The average of ten independent measures of maximum peak force was used to calculate hardness.

2.4.3 Bulk density

A seed displacement approach was used to determine bulk density (BD) [7]. Weight of the extrudates/volume displaced was used to calculate BD (g/cm^3) on a dry basis. Each value was an average of ten independent measurements.

2.4.4 Color

A spectrophotometer was used to determine the color of the extruded snacks, which were then reported as the CIELAB parameters (L*, a* and b* values) [11]. To fill a glass measurement container, the complete pieces of extrudates were randomly arranged in groups of 5 g each and placed in an upright position. Color measurements were taken at four different points on the surface of each replication. The data are presented as the average of three replications of color measurement.

2.4.5 Determination of free GABA content, total phenolic content, and antioxidant activity

Free GABA content was determined by testing in triplicate according to a previously reported method [7], using high performance liquid chromatography. Extrudates generated under specific conditions were measured in triplicate in order to validate the model. Ground extrudate (2.0 g) was combined with methanol, agitated for 30 min at room temperature with a magnetic stirrer, then centrifuged for 10 min at 2500 g. The supernatant was then collected. The residue was extracted twice further under the same conditions, yielding a 50 mL methanol extract. Total phenolic content (TPC) and antioxidant activity were measured in all extracts. TPC (mg gallic equivalent [GAE] per 100 g extrudate, db) was determined using the Folin-Ciocalteau assay. The antioxidant activity was evaluated in triplicate in the methanol resuspended extracts by the DPPH radical scavenging activity according to the method described by Chalermchaiwat et al. [7]. The absorbance from TPC and DPPH was measured with a UV visible spectrophotometer. The antioxidant activity was reported as mg GAE per 100 g extrudate, db.

2.4.6 Experimental design for optimization using RSM

The results of the proposed experimental design (expansion ratio, hardness, bulk density, and color) were subjected to regression analysis in order to determine the impacts of germinated rice flour, screw speed, and die temperature. A second-order polynomial equation was used to express the responses as a function of the independent variable, which is given in the equation below. To fit the experimental data for each response, RSM was applied for experimental data using a commercial statistical package, Design-Expert Version 13 (Statease Inc., Minneapolis, MN, USA) for generation of 3D response surface plots.

$$y_i = b_0 + \sum_{i=1}^{\infty} b_i x_i + \sum_{i=1}^{\infty} b_{ii} x_1^2 + \sum_{i=1}^{\infty}\sum_{j=1}^{\infty} b_{ij} x_i x_j ,$$

where x_i (i = 1, 2, 3) are independent variables (germinated rice flour, screw speed, and die temperature) respectively, and b_o, b_i, b_{ii}, and b_{ij} are coefficients for intercept, linear quadratic effects, and interactive effects respectively. Data were modified by multiple regression analyses. Statistical significance of each term was examined by analysis of variance (ANOVA). For each response, statistical analysis by 3D plotting was designed using design expert software (Statease). The adequacy of the regression models was checked by correlation coefficient, R^2, Fisher's F-test, and P-value; in addition, the significance of the lack-of-fit term was used to judge the fit of the model.

2.5 Sensory evaluation

The extruded snack was coated with Thai curry (green curry, Kang Kua, and Tom Yum). After coating, sensory analysis of the optimized extruded samples was carried out by untrained panelists (n=30) from Rajamangala University Technology of Srivijaya, Nakhon Si Thammarat, Thungyai area. The evaluation was based on scoring sensory aspects of the extruded snacks (color, odor, flavor, texture, and overall acceptability). A nine-point hedonic scale ranging from 1 (extremely dislike) to 9 (extremely like) was used to determine the acceptability of each snack [7].

3. Results and Discussion

3.1 Physical and chemical properties of GBR

The appearance of germinated Med Fai rice (paddy rice and brown rice flour) was observed. The color of brown rice flour from germinated Med Fai rice was found to be dark purple, and the L* and b* values increased following germination (Table 2).

The physical and chemical features of GBR is shown in Table 2. Protein and fiber content increased after germination, which was discovered to be due to the formation of new substances during germination. Fiber production is enhanced by an increase in pectic substance in the middle lamella, which results in the production of primary cell walls. These findings are consistent with those from a previous study on Sangyod Muang Phatthalung rice [12].

The GABA content of ungerminated and germinated brown rice shows that germination increases GABA content. After germination, the GABA content increased by 5.2 times (Table 3). This suggests that allowing brown rice to germinate increases the amount of this bio-active compound. Hydrolytic enzymes are triggered in germinated cereal grains and degrade starch, non-starch polysaccharides, and amino acids. During germination, high molecular weight polymers decompose, producing bio-functional compounds. Germination also improves the organoleptic properties of cereal grains by softening their texture and enhancing their flavor [12].

3.2 Properties of extrudates

Physical properties of extruded snacks were evaluated. ANOVA results and model statistics for the dependent variables are presented in Table 4.

Table 2. Physical and chemical properties of GBR.

Properties	Med Fai brown rice	Germinated Med Fai brown rice
Color		
L*	48.26±0.01	59.84±0.40
a*	4.91±0.02	3.28±0.16
b*	0.87±0.01	3.50±0.37
Particle size (μm)	250	250
Protein	7.25±0.09	10.20±0.18
Fat	2.55±0.08	1.53±0.09
Ash	1.73±0.02	1.08±0.03
Fiber	0.77±0.90	1.76±0.11
Carbohydrate	87.70±0.05	85.43±0.15

Table 3. Bioactive of GBR.

Composition (mg 100 g^{-1})	Med Fai brown rice	Germinated Med Fai brown rice
GABA	10.70±0.05	55.86±0.04
Vitamin B_1	0.66±0.03	0.96±0.01
Total phenolic content (mg GAE g DW^{-1})	0.74±0.12	0.98±0.15

Table 4. Correlation of regression equation and response value in different productions of product.

Characteristic	Regression equation	*R2*	*Adj.R2*	*p*-value
Expansion ratio	= 9.53-1.17A+2.22x10-1B+2.74x10-1C-2.07AB+1.84AC-5.0x10-3BC	0.62	0.39	0.078
Hardness	= 31.30+6.64A-7.09B-4.12C+6.35AB-12.71AC-7.32BC	0.73	0.57	0.018
Bulk density	= 2.11x10-1+7.54x10-2A+6.10x10-3B-3.15x10-2C+7.18x10-2AB-1.02x10-1AC-5.5x10-3BC	0.85	0.75	0.001
Color				
L*	= 38.03-3.57A+3.87B+6.36x10-1C	0.69	0.61	0.001
a*	= 7.47-2.35x10-1A-1.66x10-1B+8.7x10-3C+1.65x10-1AB+5.25x10-1AC+3.17x10-1BC	0.42	0.07	0.381
b*	= 19.01-4.83A+1.19B+7.84x10-1C	0.95	0.94	0.000

Remark: A = Germinated rice flour (%), B = Screw speed (rpm), C = Die temperature (°C).

3.2.1 Hardness

Hardness was defined as the maximum force necessary to break the extrudate with a probe. The harder the sample, the greater the maximum peak force required. Table 4 shows the regression coefficients for the model generated from regression analysis for hardness in terms of coded levels of the variables. The coefficient of determination (R^2) and adjusted R^2 (R^2 adj.) both had a high value of 0.73 and 0.57, respectively. GBRF and screw speed had a highly significant effect on hardness ($P \leq 0.05$), according to the correlation coefficient (r). Fig. 1 shows a response surface plot for hardness. The hardness of extrudates (5.57-49.89 N, Table 4), was impacted by both GBRF and die temperature, resulting in an increase in hardness. The inclusion of fiber in the GBRF content most likely caused the change in hardness. Fiber may increase in hardness as a result of the suppression of swollen starch and the increase in cell wall thickness, which affects extrudate porosity loss [13]. Furthermore, the temperature of the die head had a positive effect on hardness. The tendency for hardness to increase as die head temperature rises could be attributed to changes in melt chemistry generated by the increased melt temperature [14].

3.2.2 Expansion ratio

The degree of expansion in food depends on the difference between the vapor pressure of water and the atmospheric pressure, as well as the ability of the product to sustain expansion [15]. The present study found that increasing the amount of GBRF in the sample reduced the ER, which ranged from 1.60 to 4.75. It has been reported that a high amylopectin level results in a light, elastic, and uniform extrudate expansion, whereas a high amylose level resulted in a tougher product with decreased extrudate expansion [16]. Because the linear amylopectin chains align themselves on the shear field and are difficult to pull apart during expansion, amylopectin expands more than amylose. The regression coefficients are shown in Table 4. R^2 and R^2 adj. both had high values of 0.62 and 0.39, respectively. r shows that the ER is unaffected by GBRF, screw speed, and die temperature. Response surface plot for ER is shown in Fig. 2. The ER decreases as screw speed decreases. Decreased shear force and pressure within the barrel could explain this behavior [15].

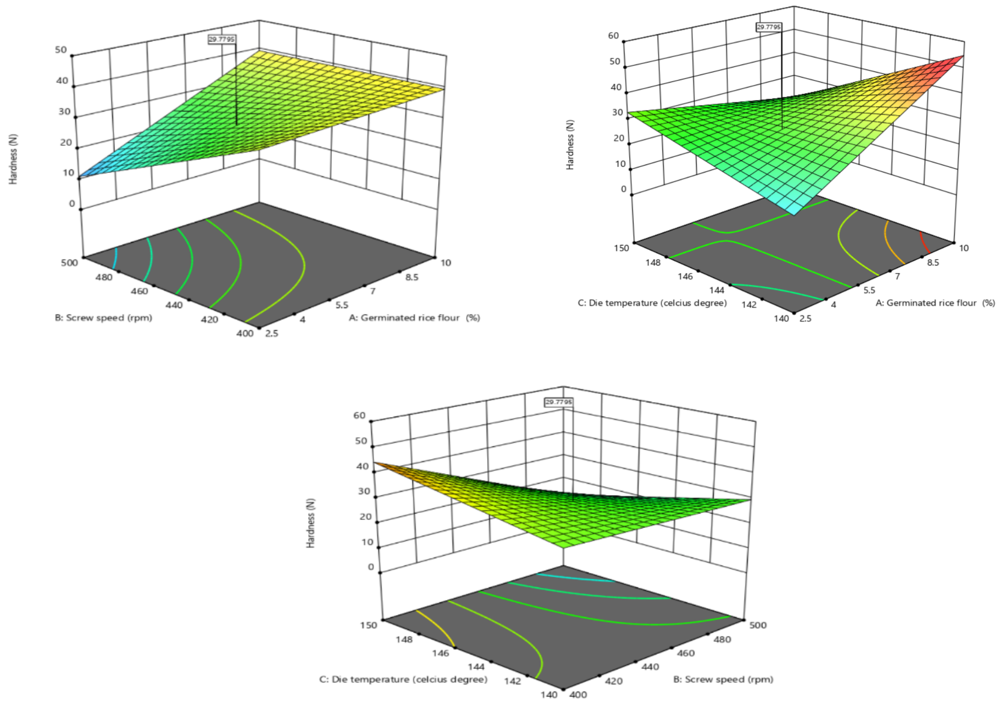

Fig. 1. The effect of GBRF, screw speed, and die temperature on hardness.

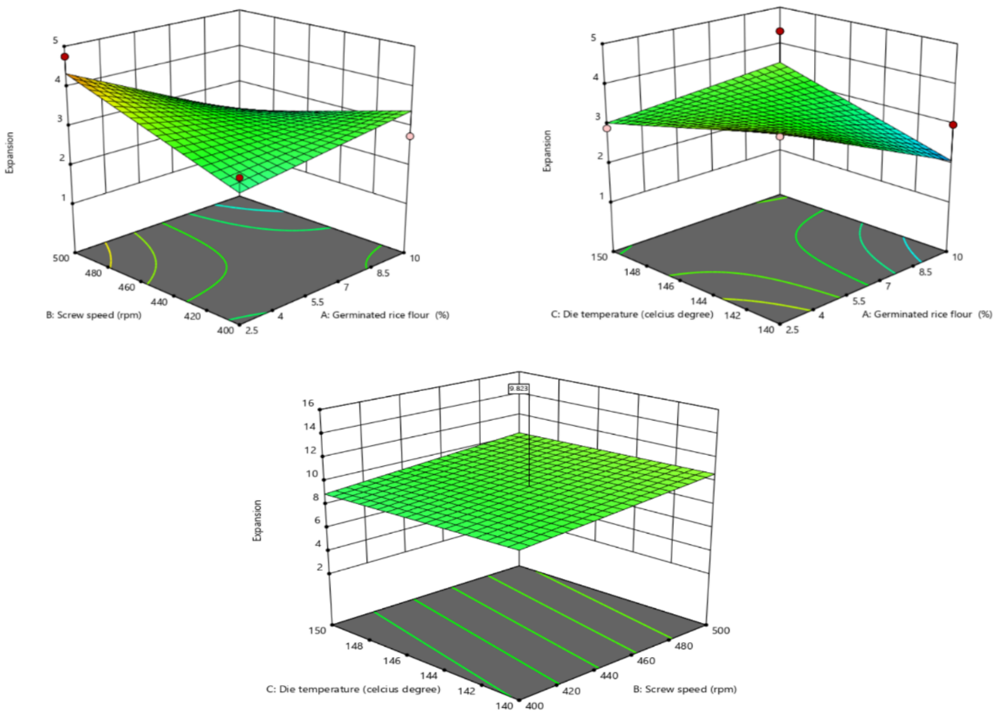

Fig. 2. The effect of GBRF, screw speed, and die temperature on ER.

3.2.3 Bulk density

BD is a puffing index that may reflect the effects of extrusion conditions on product expansion more accurately than ER [17]. The extrudates had BD values ranging from 0.06 to 0.40 g/mL. The regression coefficients are shown in Table 4. R^2 and R^2 adj. both had high values of 0.85 and 0.75, respectively. The value of r indicates that GBRF had a highly significant effect on BD ($P \leq 0.05$), whereas screw speed had no effect on BD. Fig. 3 shows the response surface plot for BD. These findings paralleled those published in another study which found that BD is caused by increasing GBRF and that BD is reduced by increasing screw speed [18]. Higher screw speeds are likely to reduce the melt viscosity of the mix while increasing the elasticity of the dough, resulting in a decrease in extrudate density [19].

3.2.4 Color

Color is an essential quality indicator in extruded starch-based puffed products. Many reactions, such as the Maillard reaction and caramelization, as well as the degree of cooking and possible pigment degradation occur during heat treatments which all affect browning. The value of L* varied from 27.37 to 49.20 with a mean value of 38.29 in the extruded samples, compared to 59.84 in the raw materials before extrusion, showing a drop in luminosity. The regression coefficients are shown in Table 4. L*, a*, and b* had high values for R^2 and R^2 adj. of 0.69 and 0.61, 0.42 and 0.07, and 0.95 and 0.94, respectively. The value of r indicated that GBRF and screw speed had a highly significant effect on L* ($p \leq 0.05$), while die temperature had no effect on L*. The response surface plot for BD is shown in Fig. 4. When GBRF incorporation was increased, the L* value decreased. In contrast, it was found that screw speed (D) and L* increased.

This can be explained by the fact that as the screw speed increases, the dough retention time decreases, reducing the extent of Maillard reaction and caramelization, and therefore increasing the L* value of the extrudates. In Fig. 4 and 5, the a* and b* values decreased as the level of GBRF in the feed blend was increased.

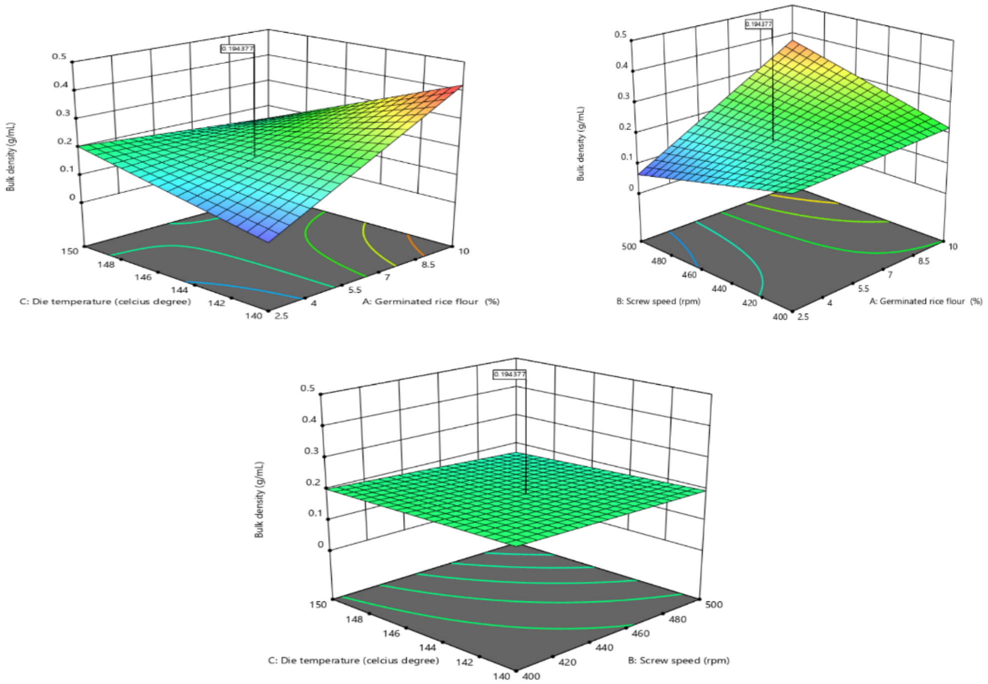

Fig. 3. The effect of GBRF, screw speed, and die temperature on BD.

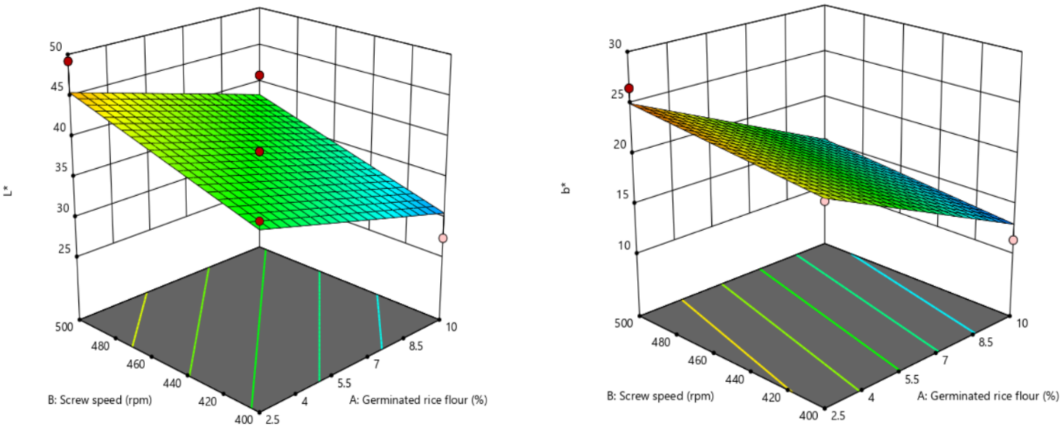

Fig. 4. The effect of GBRF, screw speed, and die temperature on L* and b*.

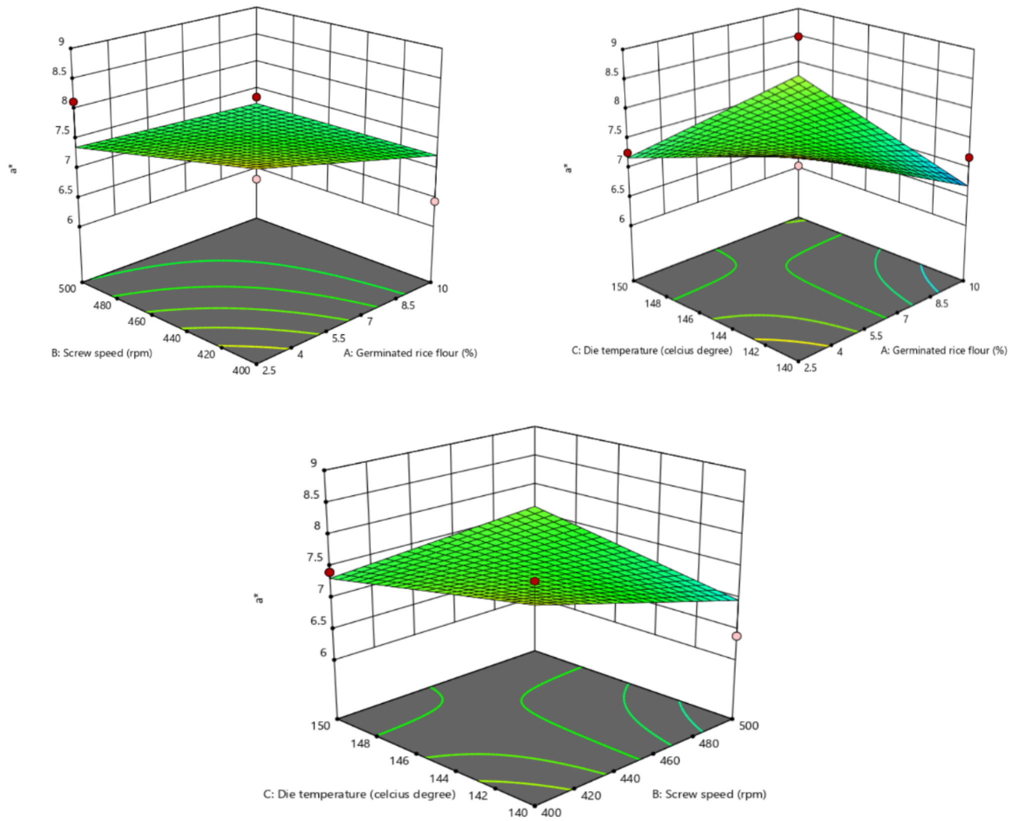

Fig. 5. The effect of GBRF, screw speed, and die temperature on a*.

3.2.5 Optimization

The best combinations of GBRF, screw speed, and die temperature for processing of Med Fai rice flour-based extrudates were determined using a graphical optimization technique in RSM software (Fig. 6).

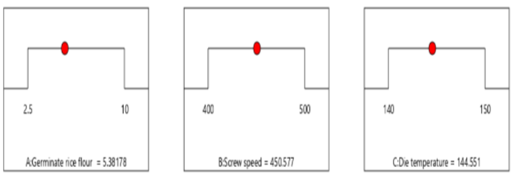

Fig. 6. The optimization of GBRF extruded snacks by RSM software.

The optimum conditions estimated by the software was 5.38% GBRF, 450.58 rpm screw speed, and 144.55°C die temperature. These conditions were the best extrusion conditions for producing extrudates with the desired physical and textural properties.

3.3 Sensory evaluation of the extruded snack coated with Thai curry

The sensory evaluation of optimized extrudate sample was carried out using a 9-point hedonic scale. The parameters such as color, odor, flavor, texture, and overall acceptability were used to understand the effect of process parameters on the organoleptic properties of the extrudate. The results from the sensory evaluation indicated that the highest overall desirability score for the extruded snacks was the one with Kang Kua coating (Table 5). The results showed that scores for color, odor, flavor, and texture were the highest for the Kang Kua-coated snack, higher than green curry and Tom Yum.

Table 5. Sensory evaluation of the extruded snack with Thai curry.

Sample	Sensory evaluation				
	Color	Odor	Flavor	Texture	Overall liking
Green curry	6.50^{b}	6.43^{b}	6.67^{b}	6.53^{b}	6.50^{b}
Kang Kua	7.63^{a}	7.53^{a}	7.57^{a}	7.57^{a}	7.67^{a}
Tom Yum	5.30^{c}	5.57^{c}	5.40^{c}	5.37^{c}	5.33^{c}

4. Conclusion

This research found that the nutritional value of Med Fai brown rice flour is increased by germination. The extrusion conditions significantly affect the properties of extrudate from germinated Med Fai brown rice flour. Additionally, germinated Med Fai brown rice flour can be used as a functional ingredient for healthy snacks. The Kang Kua flavored snack had the highest overall score.

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