Effect of extrusion conditions on the physical properties of coconut rice-based extrudates

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Abstract. Coconut meal is a by-product of coconut oil and coconut milk production. It is a rich source of dietary fiber which shows to have an important role in lowering the risk of various chronic diseases. Therefore, it is interesting to convert the coconut meal, previously recognized as a valueless by-product, into a nutritious food product. The aim of this work is to investigate the possibility of such conversion using a widely known extrusion method. The effect of extrusion variables, including the coconut meal content (0, 6, and 12\%\), glutinous rice content (5, 10 and 15\%) and screw speed of extruder (380, 400 and 420 rpm) were investigated on the properties of extruded products. Physical properties of the extrudates such as expansion ratio, density, water absorption index (WAI), water solubility index (WSI), crispness and moisture content were evaluated. Our study showed that the extrudates had expansion ratio of 2.30-2.78\%, density of 0.55-0.76 g/cm\(^3\), WAI of 4.24-5.50 g/g, WSI of 21.51-33.37\%, crispness of 16.87-27.73 kg/sec and moisture content of 6.76-8.27\%. The regression models for true density, expansion ratio, crispness, WAI and WSI were derived and statistically significant (p<0.05).

1. Introduction

Extrusion is an important process used to produce and develop a variety of foods e.g. breakfast cereals, baby foods, snacks, meat and cheese analogues, and modified starches etc. [1]. Its advantages over other processes are convenient, versatility, and ability to customize the products into various shape, texture and sensory characteristics [2]. During extrusion process, the raw materials undergo high temperature, high pressure, and accelerated structural transformation that will maintain the flavour as high quality products [3].

Broken rice is a co-product that obtained during the processing stages of rice dehulling. It has unique properties such as mild flavour, white or neutral colour, hypoallergenicity, and easy digestibility, it is suitable to be supplemented by various nutrients [4]. Chaiyakul et al. (2009) report the study of the effects of rice and glutinous rice in making potato chips products from the extrusion process. The study found that the products that contained glutinous-rice as ingredient have a better texture, while products without glutinous-rice contained have too hard texture [5].

Coconut meal is a rich source of dietary fiber (76.4\%). It is a by-product of coconut processing processes such as coconut oil extraction and coconut milk production [6]. Khuwijitjaro et al. (2012) report that 10 g of coconut meal obtained from 100 g of coconut milk production. In Thailand, there was coconut milk production around 36,000 tons every year. Therefore, coconut meal was produced approximately 3,600 tons each year [7]. Dietary fiber has been shown to have important health
implications in the prevention of the risk of chronic diseases such as cancer, cardiovascular diseases and diabetes mellitus. It also helps control weight increase [8]. Studies using dietary fiber as ingredients in various foods such as biscuits, confectionery, drinks, sauces, desserts and yogurt, found that dietary fiber acts as a bulking agent and reducing agent of the calorie content [9]. Therefore, the use of coconut meal in the food industry for the production of healthy food is an alternative way to add nutritional value to food products.

There were many studies on rice-based snack extensively while only a few of rice-based extruded enrich with coconut meal have been done. Hence, the aim of this work was to study the effects of extrusion conditions on physical properties of coconut rice-based extrudates.

2. Materials and Methods
Broken jasmine rice and glutinous rice were purchased from local market (Chang Siam, Thailand) and coconut meal was obtained from Asiatic Agro Industry Co., Ltd. Broken jasmine rice and glutinous rice were milled by hammer mill.

2.1. Preparation of blends
Blends for the extrusion process were prepared by varying coconut meal content (0, 6 and 12%) and glutinous rice content (5, 10 and 15%), while moisture content was set constant at 16% for all experiments.

2.2. Extrusion process
A single screw extruder was used for all experiments. The L/D (length: diameter) of screw was 9:1, diameter of die was 3.8 mm and temperature of extruder was set at 100°C. The screw speed of the extruder was studied at 380, 400 and 420 rpm. The extrudates were collected and dried in a tray dryer at 80°C for 10 min.

2.3. Properties analysis

2.3.1. Expansion ratio. The expansion ratio (ER) was calculated as the ratio of the extruded diameter to the die diameter (equation (1)). The diameter was measured at three different locations. Ten extrudates from each condition were analyzed.

\[
\text{Expansion ratio (ER)} = \frac{\text{extrudate diameter}}{\text{die diameter}}
\]  

(1)

2.3.2. Density (\(\rho\)). The samples were ground in order to remove most of the internal pores. Density was expressed by the equation (2).

\[
\rho = \frac{m}{V}
\]

(2)

where \(\rho\) (g/cm\(^3\)) is the density, \(m\) (g) is the mass and \(V\) (cm\(^3\)) is the volume of the solids. The experiments were done in triplicate.

2.3.3. Water absorption index (WAI) and water solubility index (WSI). Extrudates were ground and passed through the 40 mesh sieve. 2.5 g ground sample was suspended in 25 ml of distilled water at room temperature for 30 min, and then centrifuged at 4000 rpm for 15 min. Then, the sediment was weighed to calculate WAI as equation (3). The supernatant was decanted and air-dried until a constant weight and dry solid was achieved. The WSI was calculated as equation (4) [10].

\[
\text{WAI} (\text{g/g}) = \frac{\text{weight of sediment}}{\text{weight of dry solids}}
\]

(3)

\[
\text{WSI} (%) = \frac{\text{weight of dissolved solids in supernatant}}{\text{weight of dry solids}}
\]

(4)

2.3.4. Crispness. Crispness of the extrudates was determined using a Texture Analyzer (Serial No.4650, TEE version no.2.64 UK) fitted with a 50 kg load cell. Ten extruded of approximately 5 cm
in length were placed on a platform and penetrated perpendicularly by a 2 mm cylindrical probe. The probe was set at a test speed of 3 mm/s for a distance of 14 mm.

2.3.5. Moisture content (MC). The moisture content of extruded was determined using a hot-air oven method and calculated the amount of evaporated moisture based on AOAC, 2005 [11].

2.4. Experimental design and data analysis
The effects of three independent variables, including coconut meal content (% X1), glutinous rice content (% X2) and screw speed (rpm, X3), on the properties of the extrudates were studied. Each variable was set at three different levels. A total number of 17 experiments with 5 replicates of the central point were conducted and designed by Box Behnken design (BBD). Second order polynomial model was applied, which is given as:

\[ Y = \beta_0 + \sum_{i=1}^{3} \beta_i X_i + \sum_{i=1}^{3} \beta_{ii} X_i^2 + \sum_{i=1}^{3} \sum_{j=i+1}^{3} \beta_{ij} X_i X_j \]  

where Y is the physical properties of extruded, \(\beta_0\), \(\beta_i\), \(\beta_{ii}\) and \(\beta_{ij}\) are the constant and coefficient for linear, quadratic and interaction terms. \(X_i\) and \(X_j\) are the coded values of the variables.

The data were analysed with an analysis of variance method (ANOVA) and response surface plot using Design Expert v.11.0.5. A probability of \(p<0.05\) was used to determine the statistical significance of the results.

3. Results and Discussion
Effect on the rice-based extrudates were evaluated by varying coconut meal content, glutinous rice content and screw speed at different levels (0-12%, 5-15% and 380-420 rpm respectively), and the result are show in table 1. Statistical analysis of extruded’s physical properties are shown in table 2. The regression models for expansion ratio, density, WAI, WSI and crispness were statistically significant \((p<0.05)\). However, the regression model for moisture content was not significant at \(p<0.05\). Moisture content was found to be in the range of 6.76-8.27%, and fiber of extruded in range of 0.32-9.51%.

Table 1. Box Behnken design with process variables and experimental results of extruded products.

| Exp. no. | Coconut meal content (%) | Glutinous rice content (%) | Screw speed (rpm) | ER (%) | \(\rho\) (g/cm³) | WAI (g/g) | WSI (%) | Crispness (kg/sec) | Moisture content (%) |
|----------|--------------------------|----------------------------|-------------------|--------|-----------------|-----------|---------|-------------------|-------------------|
| 1        | 12                       | 10                         | 380               | 2.55±0.07 | 0.61±0.00 | 4.42±0.02 | 27.97±0.71 | 18.54±3.63 | 7.75±0.04 |
| 2        | 0                        | 15                         | 400               | 2.66±0.05 | 0.71±0.01 | 4.95±0.03 | 27.60±0.12 | 19.65±3.08 | 7.27±0.04 |
| 3        | 6                        | 10                         | 400               | 2.73±0.07 | 0.67±0.01 | 4.82±0.00 | 26.37±0.49 | 21.04±2.90 | 7.15±0.02 |
| 4        | 6                        | 15                         | 420               | 2.62±0.12 | 0.71±0.00 | 4.95±0.02 | 25.84±0.53 | 18.90±3.31 | 7.69±0.03 |
| 5        | 6                        | 10                         | 400               | 2.54±0.08 | 0.70±0.01 | 4.84±0.01 | 26.21±0.37 | 21.25±6.47 | 7.14±0.02 |
| 6        | 6                        | 15                         | 400               | 2.61±0.08 | 0.71±0.01 | 4.89±0.06 | 26.11±0.23 | 20.14±3.30 | 7.11±0.07 |
| 7        | 6                        | 10                         | 400               | 2.58±0.06 | 0.72±0.01 | 4.90±0.03 | 26.06±0.47 | 20.29±7.98 | 7.17±0.04 |
| 8        | 0                        | 10                         | 380               | 2.71±0.04 | 0.71±0.02 | 5.05±0.02 | 26.94±0.52 | 17.44±3.61 | 7.09±0.04 |
| 9        | 6                        | 15                         | 380               | 2.54±0.09 | 0.69±0.01 | 4.86±0.07 | 25.94±0.86 | 21.46±3.55 | 7.16±0.07 |
| 10       | 6                        | 5                          | 420               | 2.48±0.08 | 0.76±0.01 | 5.51±0.03 | 21.51±0.72 | 20.71±7.57 | 8.27±0.03 |
| 11       | 6                        | 5                          | 380               | 2.68±0.09 | 0.73±0.00 | 5.27±0.02 | 23.71±0.41 | 21.42±4.55 | 7.62±0.02 |
| 12       | 0                        | 5                          | 400               | 2.61±0.07 | 0.74±0.01 | 5.22±0.05 | 25.91±0.19 | 19.33±4.63 | 6.97±0.02 |
| 13       | 12                       | 10                         | 420               | 2.30±0.04 | 0.55±0.00 | 4.61±0.02 | 27.26±0.37 | 19.91±3.90 | 6.79±0.06 |
| 14       | 12                       | 5                          | 400               | 2.33±0.11 | 0.67±0.00 | 4.77±0.12 | 24.65±0.68 | 27.73±7.20 | 7.59±0.03 |
| 15       | 12                       | 15                         | 400               | 2.42±0.04 | 0.57±0.01 | 4.24±0.03 | 33.37±0.87 | 18.53±2.96 | 6.76±0.15 |
| 16       | 0                        | 10                         | 420               | 2.78±0.09 | 0.71±0.01 | 5.15±0.02 | 26.16±0.51 | 16.87±2.98 | 7.09±0.05 |
| 17       | 6                        | 10                         | 400               | 2.69±0.05 | 0.72±0.00 | 4.90±0.09 | 26.21±0.13 | 21.55±4.57 | 7.13±0.04 |
Table 2. Estimated regression coefficients of the second order polynomial for the variables.

| Variables | ER     | ρ      | WAI    | WSI    | Crispness | MC    |
|-----------|--------|--------|--------|--------|-----------|-------|
| Constant  | 2.63   | 0.7015 | 4.87   | 26.19  | 20.85     | 7.14  |
| X₁        | -0.1442*| -0.0589*| -0.2909*| 0.8295*| 1.43*     | 0.0601|
| X₂        | 0.0184  | -0.0267*| -0.2201*| 2.21*  | -1.33*     | -0.1958|
| X₃        | -0.0380 | -0.0017 | 0.0767*| -0.4740 | -0.3086   | 0.0280|
| (X₁)²     | -0.0611 | -0.0545*| -0.2072*| 2.26*  | -0.9865   | -0.2482|
| (X₂)²     | -0.0686 | 0.0249  | 0.1330*| -0.5724 | 1.44      | 0.2551|
| (X₃)²     | 0.0172  | -0.0052 | 0.1459*| -1.37*  | -1.67*     | 0.2872|
| (X₁)(X₂)  | 0.0109  | -0.0180 | -0.0656*| 1.76*  | -2.38*     | -0.2791|
| (X₁)(X₃)  | -0.0823*| -0.0149 | 0.0191  | 0.0168  | 0.4855     | -0.2415|
| (X₂)(X₃)  | 0.0688  | -0.0055 | -0.0335| 0.5206  | -0.4617   | -0.0286|
| R-Squared | 0.9037  | 0.9326  | 0.9941  | 0.9695  | 0.8775     | 0.7390|
| Std. Error| 0.0633  | 0.0228  | 0.0353  | 0.6224  | 1.26       | 0.2969|
| p-value   | 0.0079  | 0.0025  | 0.00    | 0.0002  | 0.0169     | 0.1553|

*Significant at p<0.05

3.1. Expansion ratio

Expansion is a desirable variable, indeed the higher expansion ratio is suitable for extruded snack products. Generally, expansion ratio was affected by various extrusion conditions such as moisture content of feed, temperature of extruder, die diameter, feed rate and screw speed [12]. In this study, the regression analysis report (table 2) showed that coconut meal content and screw speed had a negative linear and quadratic effect on ER of extruded, while glutinous rice content had positive linear and quadratic effects of screw speed on ER. The interactive effect of coconut meal and glutinous rice content and glutinous rice content and screw speed showed positive interactive effect. Response surface plot (figure 1a) shows that the increased coconut meal content and screw speed led to decrease of ER. Similar results were reported by Arivalagan et al. (2018) for coconut haustorium based extruded. Arivalagan et al. (2018) also investigated the effect of coconut haustorium content on ER. Found that the highest ER obtained from using 100% rice (3.311±0.126%) and it down from 3.044-1.571% when increased coconut haustorium from 10-30%. Higher water holding capacity of fiber reduces the water loss at the die and thus reduces its ability for expansion [2].

3.2. Density

True density is a constant, fundamental characteristic of the dry material which is determined by the physicochemical composition of a biological material [13]. In this study the extrudates show density in range of 0.55-0.76 g/cm³. Low density was obtained at the lowest values of all of three variables. Regression analysis showed that, with the increase in the coconut meal and glutinous rice content, significant negative effect on density was observed (table 2). Response surface plot for density are given in figure 1b. Raghavendra et al. (2011) studied pea–rice based extruded products fortified with guar gum and locust bean gum found that the inclusion of guar gum and locust bean gum decreased the true density up to 15% [9].

3.3. WAI and WSI

WAI is used to quantify the range of starch denaturation during extrusion cooking. WAI can indicate the dispersion of starch in excess water. Dispersion can be increased by the rating of starch denaturation due to gelatinization and extrusion induced fragmentation [1]. WAI was found to be in the range of 4.24-5.50 g/g. The coconut meal content, glutinous rice content and screw speed have significant effects on the WAI of the extruded. The negative effect of the linear terms of coconut meal and glutinous rice content indicated that WAI decreased when increased coconut meal and glutinous rice content, while positive coefficients of linear terms of screw speed resulted to increase in WAI.
Response surface plots (figure 1c) showed that with the increase in coconut meal and glutinous rice content there was a decrease in WAI, and similar trends were observed with screw speed.

WSI is used to determine the amount of polysaccharides that are soluble after excess of water has been added, WSI is often used as an indicator of degradation of molecular components [12]. In this work, WSI occurred in ranged of 21.51-33.37% (table 1). From the regression analysis report, it was found that WSI varied significantly with screw speed. Response surface plot on WSI as affected by process conditions is shown in figure 1d.

Arivalagan et al. (2018) used coconut haustorium in rice and corn extrudates. They study found the increase in coconut haustorium content in the extruded decreased the WAI while increased the WSI [2].

3.4. Crispness
Texture is one of the most important quality features of extruded products, which is the key parameter that drives a consumer preference. Among the texture attributes of food products, crispness is one of the most major and desirable textural attributes in quality assessment of extruded products [4]. The range of crispness was found to be 16.87-27.73 kg.sec. Effect of process variables on the crispness of extruded are presented in table 1. Regression analysis shows that crispness of extrudates was significantly affected by coconut meal and glutinous rice contents (table 2). Response surface plot is shown in figure 1e that crispness was high for high coconut meal content and low for high glutinous rice content.

4. Conclusion
This study investigated the physical properties of extrudates under varying coconut meal contents, glutinous rice contents and screw speed by using single screw extruder. The results of extrudates characteristics were shown expansion ratio of 2.30-2.78%, density of 0.55-0.76 g/cm³, WAI of 4.24-5.50 g/g, WSI of 21.51-33.37%, crispness of 16.87-27.73 kg.sec. The regression models for expansion ratio, density, WAI, WSI and crispness were statistically significant ($p<0.05$). Therefore, this information could be applied to develop an extruded product further.
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