The optimization of extrusion condition of Phatthalung Sungyod rice extrudate: a preliminary study

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Abstract
Phatthalung Sungyod rice flour was supplied to extrude in a co-rotating twin screw extruder. The effects of extrusion conditions such as, barrel temperature (135-165°C), screw speed (300-400 rpm) and feed moisture contents (12.5-17.5%) on physicochemical properties of rice extrudate and the optimized condition were studied by the use of response surface methodology (RSM). The second-order polynomials were used to model the product response as a function of process variables and the multiple regression equations were obtained to describe effect of each variable on product responses. Barrel temperature, screw speed and feed moisture content had significant effects on density, expansion ratio, water absorption index (WAI), water solubility index (WSI) and hardness of rice extrudate. They were most affected by the changes in the level of feed moisture content and barrel temperature. At low feed moisture content and high temperature, rice extrudate appeared to be expanded with low density and more crispness. WAI and WSI of extrudate increased with increase barrel temperature and decrease feed moisture content. The hardness of rice extrudate varied between 23.31 and 54.24 N. At the highest feed moisture content, the lowest barrel temperature and screw speed, the highest value of product’s hardness was obtained. The optimized extrusion condition for produced rice extrudate was at low feed moisture (12.5%), low screw speed (300 rpm) and high barrel temperature (165°C). With this condition, the well expansion, low product density and more crispness of extruded snack were obtained.

Introduction

Snacks are widely consumed as convenience food products. They can be produced using a wide variety of processing techniques among which is extrusion cooking. Extrusion cooking has become one of the most popular technologies in food processing. It is a low cost, high temperature short time (HTST) process, use worldwide for processing of a number of food products (Singh et al., 2007a). It is a powerful processing operation, which utilizes high temperature, pressure, and shear force to produce highly expanded, low-density products with unique texture properties. Extrusion of snack foods demands close control of many variables such as feed moisture, feed composition, feed particle size, feed rate, barrel temperature, screw speed, screw configuration, and die geometry. These process variables determine the extent of macromolecular transformations during extrusion, which in turn influence the rheological properties of the food melt in the extruder and the physical characteristics of extrudates. Consequently, changing the factors can influence extrusion behavior and the quality of extruded products (Frame, 1994; Reyes-Moreno et al., 2003; Singh et al., 2007b). Physical characteristics such as expansion, density, and hardness are important parameters to evaluate the consumer acceptability of the final product (Patil et al., 2007).

To produce the puff extruded snack, starch is the main constituent and is responsible for most of their structural attributes. Most raw materials have been used to develop various types of snack foods. The basic component of investigation is starch from corn, wheat, rice and potato, which is the key component for the product structuring and foaming (Bhattacharya et al., 1986; Bhattacharya, 1997; Matthey and Hanna, 1997; Sun and Muthukumarappan, 2002; Fernandez-Gutierrez et al., 2004; Singh et al., 2007a; Anton et al., 2009). Among these, rice has some special properties and it can widely use in the food industry due to the search for new sources of starches with special properties to improve the quality of products and processes. It has excellent expansion properties.
because of its high starch content and is well suited to thermal extrusion process.

In southern Thailand, there are much more than 4,000 varieties of the traditional rice Phatthalung Sungyod rice is a rice variety which most produce in Songkla Lake Basin, covering three provinces, Nakhon Si Thammarat, Songkhla and Phatthalung. Phatthalung Sungyod rice is a pigmented rice, which it contain a natural colorant, called anthocyanin. A commonly found anthocyanin in red rice is acetylated procyanidins, which is reported to possess a free radical scavenging activity. The contents of GABA (γ-aminobutyric acid), γ-Oryzanol and Ferulic acid were found in Phatthalung Sungyod rice, as reported by Banchuen et al. (2010).

According to the extrusion conditions and feed composition affect structural and textural characteristics of extruded snacks. Recently, there are several studies investigating the effect of extrusion conditions on structural and textural characteristics of starch-based extrudates (Onwulata et al., 2001; Fernandez-Gutierrez et al., 2004; Ding et al., 2006; Chaiyakul et al., 2009; Meng et al., 2010). Therefore, the objective of this study was to evaluate the optimized extrusion condition for producing extrudate from Phatthalung Sungyod rice. The changes in physicochemical properties of rice extrude (expansion ratio, density, WAI, WSI and hardness), as resulted from extrusion conditions (barrel temperature, screw speed and feed moisture) were reported and described by response surface methodology.

Materials and Methods

Sample preparation

Rice grain was obtained from Phatthalung province, southern Thailand. It was harvested in 2013. After harvested, rice were dried as a commercial method, dehulled and processed to obtain rice flour. The particle size of rice flour was range between 40-60 mesh and its moisture content was 11.27% (db.) according to the method of AOAC (2000).

Extrusion cooking

The extrusion trials were performed with an intermeshing co-rotating twin screw extruder (Hermann Berstorff Laboratory, The Twin Screw Extruder ZE 25 x 33D). This extruder comprises of 7 parts of barrel, end with a 24.5 mm thick die plate with one slit (1 mm × 20 mm) and the barrel length to diameter ratio (L/D) of the extruder is 870:25. This screw profile is made up of conveying self-wiping elements except for a section consisting of short reverse at the end of barrel. The material was fed into the extruder using a volumetric twin screw feeder (K-Tron soderg AG 5702, type 20, Switzerland). Barrel temperature (135, 150 and 165°C), screw speed (300, 350 and 400 rpm) and feed moisture (12.5, 15 and 17.5%) were varied, the extrusion conditions are shown on Table 1. After the steady-state conditions, the extrusion response parameters die temperature and die pressure were constant, extrudates were collected and suddenly dried in hot air oven for 5 min, then packed in Nylon/LLDPE plastic bags and stored at room temperature until analyze for further properties.

Bulk density

The apparent density was determined by measuring the actual dimensions of the extrudates. The diameter of extrudates was measured with a Vernier caliper (Mitutoyo, Tokyo, Japan). The apparent density of extrudates was determined using the equation:

\[ \rho_{app} = \frac{4 \times m}{\pi \times d^2 \times L} \]

where \( m \) is the mass of the samples (g), \( d \) is the diameter (cm) and \( L \) is the length of extrudate (cm). The results are the average of 10 replicate measurements.

Expansion ratio

To determine the expansion ratio (ER), the cross-sectional diameter of the extrudates was measured with a Vernier caliper (Mitutoyo, Tokyo, Japan). The expansion ratio was calculated as the cross-sectional diameter of the extrudate divided by the diameter of the die opening (Ding et al., 2005; Onwulata et al., 2001). It was obtained from 10 random samples for each extrusion condition.

Water absorption (WAI) and water solubility index (WSI)

The WAI and WSI were measured as a method of Anderson et al. (1969). The extrudates were ground and 2.5 g of sample was suspended in 25 ml of distilled water, the glass rod was used to break up any lumps. After stirring for 30 min, the dispersion was rinsed into a centrifuge tube and centrifuged at 5000 rpm for 10 min. The supernatant was decanted for determination of its solids content and the sediment was weighed. WAI was calculated using the equation:

\[ WAI(g/g, db)=\frac{\text{Weight of gel (g)}}{\text{Weight of ground dry sample (g)}} \]

The supernatant liquid from the WAI determination was dried at 105°C until constant weight
was reached. The amount of dried solid recovered from evaporating the supernatant was expressed as a percentage of dry solids in the 2.5 g ground dry sample and defined as water solubility index (WSI).

\[
WSI (\%) = \frac{\text{Dry solid (g)}}{\text{Weight of ground dry sample (g)}} \times 100
\]

**Hardness**

The hardness of samples was measured using Stable Microsystems TA-XT2i Texture Analyzer (Texture Technologies Corp., Scarsdale, NY, USA). It was fitted with a 50 kg load cell. Samples were prepared and packed into a Kramer shear cell. The Kramer probe (5 blades, 3 mm thick, 64 mm high, 82 mm wide, 11 mm apart) was set to move at a test speed of 2.0 mm/s for a distance of 50 mm. The maximum force needed to break the samples was recorded.

**Experimental design and statistical analysis**

In this study, the response surface methodology (RSM) was used to investigate the optimized and the effect of extrusion conditions on the product responses of rice-based snack. The actual level ranges were selected according to the preliminary trial and literatures for suitable extrusion cooking. The outline of experimental design with the actual levels is presented in Table 1. The independent variables considered for this study were barrel temperature of the last zone (135–165°C), screw speed (300–400 rpm) and feed moisture content (12.5–17.5%). Face Centered Central Composite Design was employed to determine the extrusion conditions (Myers, 1971). Experiments were randomized in order to minimize the systematic bias in the observed responses due to extraneous factors.

Product responses (bulk density, expansion ratio, water absorption index (WAI), water solubility index (WSI) and hardness) were obtained as results of the proposed experimental design were subjected to regression analysis in order to assess the effects of feed moisture content, screw speed, and barrel temperature. A polynomial regression model

\[
Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_{11}X_1^2 + \beta_{22}X_2^2 + \beta_{33}X_3^2 + \beta_{12}X_1X_2 + \beta_{13}X_1X_3 + \beta_{23}X_2X_3
\]

The dependent variables were established to fit the experimental data for each response and computed by using Design expert (version 7.0), where \(X_1, X_2, \) and \(X_3\) are linear, quadratic, and interaction effect of the input variables which influence the response \(Y\), respectively. \(\beta_0, \beta_1, \) and \(\beta_2\) are the regression coefficients to be determined. The response surface plots for these models were plotted as a function of two variables.

**Results and Discussion**

The effects of extrusion conditions, such as, barrel temperature, screw speed and feed moisture content on physicochemical properties of rice extrudates were studied. The difference in operation conditions of extruder has profound affected on properties of rice extrudates. The regression models of physicochemical properties of rice extrudates, such as, density, expansion ratio, WAI, WSI and hardness were significant \((P < 0.05)\), with a high coefficient for determination \((R^2 = 0.98, 0.96, 0.96, 0.99 \) and 0.68, respectively). All of model showed the non-significant lack of fit \((P > 0.05)\).

**Bulk density**

Bulk density was significantly affected by the quadratic \((P < 0.05)\) effects of feed moisture content and barrel temperature. The response surface plots of product density are shown in Figure 1. The product bulk density increased with increase in feed moisture, whereas decreased with increase in screw speed and barrel temperature. The density of extrudates varied between 0.35 and 0.64 g/cm³. A similar result was observed in the study of Meng et al. (2010). They reported that the low density, a desirable characteristic of a chickpea flour-based expanded products, was obtained at low feed moisture, high screw speed and barrel temperature. The bulk density of extrudate also describes the degree of expansion undergone by the melt as it exits the extruder. The bulk density is used as a measurement of volumetric expansion which it would has less variability than the other types of expansion (Dogan and Karwe, 2003; Meng et al., 2010).

**Expansion ratio**

Expansion ratio is a measurement of expansion in diameter of extrudate. According to extrusion conditions were used in this study, the expansion ratio of extrudates was in the between 2.19 and 4.01. The results from regression analysis showed a significant \((P < 0.05)\) effect of feed moisture content and barrel temperature on expansion of extrudates as main effect whereas there was a non-significant \((P > 0.05)\) effect of screw speed on expansion. Feed moisture content has a significant negative quadratic effect, while barrel temperature and screw speed have a significant positive quadratic effect \((P < 0.05)\) on the expansion of rice extrudates. It was observed from the response surface plot (Figure 2) that products showed a high in
Table 1. Experimental design for extrusion experiments

<table>
<thead>
<tr>
<th>Run No.</th>
<th>X1</th>
<th>X2</th>
<th>X3</th>
<th>Barrel temperature (°C)</th>
<th>Screw speed (rpm)</th>
<th>Feed moisture content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>155</td>
<td>300</td>
<td>12.5</td>
</tr>
<tr>
<td>2</td>
<td>-1</td>
<td>0</td>
<td>0</td>
<td>155</td>
<td>350</td>
<td>15.0</td>
</tr>
<tr>
<td>3</td>
<td>-1</td>
<td>1</td>
<td>-1</td>
<td>155</td>
<td>400</td>
<td>12.5</td>
</tr>
<tr>
<td>4</td>
<td>-1</td>
<td>1</td>
<td>1</td>
<td>155</td>
<td>400</td>
<td>17.5</td>
</tr>
<tr>
<td>5</td>
<td>-1</td>
<td>-1</td>
<td>1</td>
<td>155</td>
<td>300</td>
<td>17.5</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>150</td>
<td>400</td>
<td>15.0</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>0</td>
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<td>350</td>
<td>17.5</td>
</tr>
<tr>
<td>8</td>
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<td>-1</td>
<td>0</td>
<td>150</td>
<td>300</td>
<td>15.0</td>
</tr>
<tr>
<td>9</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>150</td>
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<td>150</td>
<td>350</td>
<td>15.0</td>
</tr>
<tr>
<td>11</td>
<td>0</td>
<td>0</td>
<td>-1</td>
<td>150</td>
<td>350</td>
<td>12.5</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>165</td>
<td>350</td>
<td>15.0</td>
</tr>
<tr>
<td>13</td>
<td>1</td>
<td>-1</td>
<td>-1</td>
<td>165</td>
<td>300</td>
<td>12.5</td>
</tr>
<tr>
<td>14</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>165</td>
<td>400</td>
<td>17.5</td>
</tr>
<tr>
<td>15</td>
<td>1</td>
<td>-1</td>
<td>1</td>
<td>165</td>
<td>300</td>
<td>17.5</td>
</tr>
<tr>
<td>16</td>
<td>1</td>
<td>1</td>
<td>-1</td>
<td>165</td>
<td>400</td>
<td>12.5</td>
</tr>
</tbody>
</table>

Table 2. The regression parameter coefficient product properties using independent variables barrel temperature (X1), screw speed (X2) and feed moisture content (X3) of Phathalung Sungyod rice extrudates

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Density [g/cm³]</th>
<th>Expansion [%)</th>
<th>Water absorption index (WAI) [g/g, db]</th>
<th>Water solubility index (WSI) [%]</th>
<th>Hardness [N]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>0.4095</td>
<td>3.0578</td>
<td>5.2034</td>
<td>49.8058</td>
<td>22.609</td>
</tr>
<tr>
<td>Barrel temperature (X1)</td>
<td>-0.100</td>
<td>0.0505</td>
<td>0.0540</td>
<td>0.7870</td>
<td>-1.1830</td>
</tr>
<tr>
<td>Screw speed (X2)</td>
<td>-0.0070</td>
<td>0.0040</td>
<td>-0.1130</td>
<td>-1.3770</td>
<td>0.7850</td>
</tr>
<tr>
<td>Feed moisture (X3)</td>
<td>0.1520</td>
<td>-0.5730</td>
<td>-0.6420</td>
<td>-14.5040</td>
<td>14.2700</td>
</tr>
<tr>
<td>Barrel temperature × Screw speed (X1) × (X2)</td>
<td>0.0063</td>
<td>-0.0100</td>
<td>0.0150</td>
<td>0.0187</td>
<td>0.1483</td>
</tr>
<tr>
<td>Barrel temperature × Feed moisture (X1) × (X3)</td>
<td>-0.0013</td>
<td>0.0700</td>
<td>-0.0025</td>
<td>0.0212</td>
<td>0.2988</td>
</tr>
<tr>
<td>Screw speed × Feed moisture (X2) × (X3)</td>
<td>-0.0008</td>
<td>0.0475</td>
<td>0.0075</td>
<td>0.0037</td>
<td>-0.9238</td>
</tr>
<tr>
<td>Barrel temperature × Barrel temperature (X1)²</td>
<td>-0.0137</td>
<td>0.1256</td>
<td>-0.1252</td>
<td>0.0093</td>
<td>-0.0138</td>
</tr>
<tr>
<td>Screw speed × Screw speed (X2)²</td>
<td>0.0283</td>
<td>-0.1714</td>
<td>0.1908</td>
<td>1.1543</td>
<td>0.2832</td>
</tr>
<tr>
<td>Feed moisture × Feed moisture (X3)²</td>
<td>0.0333</td>
<td>-0.6164</td>
<td>-0.2252</td>
<td>-4.9007</td>
<td>0.3412</td>
</tr>
<tr>
<td>P-value for model</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>β</td>
<td>0.98</td>
<td>0.06</td>
<td>0.96</td>
<td>0.99</td>
<td>0.68</td>
</tr>
<tr>
<td>P-value for lack of fit</td>
<td>0.21</td>
<td>0.08</td>
<td>0.26</td>
<td>0.54</td>
<td>0.78</td>
</tr>
</tbody>
</table>

Water absorption (WAI) and water solubility indices (WSI)

WAI of extrudates ranged from 4.18 to 5.68 g/g dry sample. The significant negative coefficient (P < 0.05) of the linear terms of feed moisture and screw speed level indicated that WAI decreased with increase in these variables while positive coefficient of the linear terms of barrel temperature resulted increase in WAI (P > 0.05). The WAI measures the volume occupied by the granule or starch polymer after swelling in excess water. While the WSI determines the amount of free polysaccharide or polysaccharide released from the granule after addition of excess water (Sriburi and Hill, 2000; Altan et al., 2008). Similar results were reported by expansion ratio at low level of feed moisture content. However, a small increase in expansion ratio was observed with the increase in barrel temperature and screw speed. This was in agreement with the study of Ding et al. (2005) and Ding et al. (2006). They reported that the extrudate expansion was found to be most dependent on feed moisture. Increased feed moisture leads to a sharp decrease in the expansion of extrudate. However, screw speed and barrel temperature also have significant effects on their expansion. A small increase in expansion ratio was noticed with the increase in barrel temperature and screw speed.

Bhattacharya (1997), Ding et al. (2006) and Altan et al. (2008). They reported that the significantly decrease in WAI of extrudate as the increase in barrel temperature. A decrease in WAI with increase in temperature was probably due to decomposition or degradation of starch. The WAI decreases with increasing temperature if dextrinization or starch melting prevails over the gelatinization phenomenon (Ding et al., 2006). The WSI of extrudate ranged between 20.25 and 53.43% (db). It increased with increase in barrel temperature (P > 0.05), whereas negative coefficient effects (P < 0.05) of feed moisture and screw speed were observed. Gujska and Khan (1990) reported a significant increase in WSI with increase in extrusion temperature for the high starch fraction of different beans. Increase in WSI, with decrease in moisture content, may be attributed to higher degradation of starch (Anderson et al., 1969). Similar effects of decrease in feed moisture on WSI have been previously reported for starch, maize grits,
rice and wheat (Singh and Smith, 1997; Kirby \textit{et al.}, 1988; Bryant \textit{et al.}, 2001).

\textbf{Hardness}

Hardness of extrudates was significantly affected by quadratic effects of barrel temperature, screw speed and feed moisture content variables. Feed moisture content and screw speed had also significant positive effect ($P < 0.05$) on extrudate hardness, while barrel temperature had negative effect on hardness of extrudate products. The results are shown in Table 2. The response surface plots (Figure 3) showed that hardness decreased with decreasing feed moisture content and screw speed, whereas, with increasing barrel temperature, the hardness decreased. A positive correlation between bulk density and hardness has been reported by many researchers suggesting that a low density product naturally offers low hardness (Bhattacharya, 1997; Ding \textit{et al.}, 2006; Altan \textit{et al.}, 2008; Meng \textit{et al.}, 2010). The hardness of extrudates ranged from 20.13 to 54.24 N. The low hardness is a favour property of extrudates. It was observed at low feed moisture, screw speed and high barrel temperature. The hardness of expanded extrudates is a perception of the human being and is associated with expansion and cell structure of the product. The hardness is the peak force required for a probe or parallel blades to penetrate the extrudate (Meng \textit{et al.}, 2010). The higher the value of maximum peak force required, which means the more force required to breakdown the sample, the higher the hardness of the sample to fracture (Altan \textit{et al.}, 2008). Similar result was reported by Chaiyakul \textit{et al.} (2009). They reported that feed moisture and barrel temperature have a significant effect on the hardness of high protein glutinous rice-based extrudate. Increasing feed moisture content increased the breaking strength index of the extrudate. In contrast, increasing temperature, the breaking strength index of extrudate decreased. The decrease in hardness with increasing barrel temperature is in line with the results of bulk density reduction, whereas, the expansion of extrudate increased. Several studies reported the high correlation between bulk density and hardness that low density product naturally offers low hardness (Bhattacharya, 1997; Ding \textit{et al.}, 2006; Altan \textit{et al.}, 2008; Meng \textit{et al.}, 2010). The effect of screw speed on hardness might be through its influence on extrudate expansion. The decrease in hardness with increasing screw speed was also observed in corn- and barley-based extrudates (Liu \textit{et al.}, 2000; Altan \textit{et al.}, 2008). The increase in screw speed expected to lower the melt viscosity of the mix resulting in a less dense, softer extrudate (Ding \textit{et al.}, 2006).

\textbf{Conclusions}

Change of extrusion conditions, especially, feed moisture, barrel temperature and screw speed affected the physicochemical properties of rice extrudate. The high expansion ratio and low bulk density were observed at high barrel temperature, high screw speed and low feed moisture. Increased feed moisture and screw speed increased in hardness of extrudate, while increased in barrel temperature hardness of product was decreased. Feed moisture and screw speed have negative effects on WAI and WSI, whereas barrel temperature has positive effect. The products with high expansion ratio and low product density, which generally are good characteristics of extruded snack, were produced at medium extrusion temperature, high screw speed, and low feed moisture.

\textbf{Acknowledgments}

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\textbf{References}


