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Effects of extrusion variables on extrudate characteristics from corn-based enriched with soybean residue

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Abstract. Soybean residue is a food processing by-product of soya milk or tofu production process. It consists of rich protein and fiber. As a result, reprocessing soybean residue as human food can be a worthwhile alternative. This research focuses on studying the effects of extrusion process and the extrudate characteristics. The mixture of corn grit and soybean residue flour was extruded by single-screw extruder to produce high protein snack. Experimental design was performed by Box-Behnken design and Response surface methodology (RSM) was used to assess the effects on extrusion variables, including screw speed (370-430 RPM), soybean residue flour content (20-40%) and feed moisture (14-18%) on the properties of the extrudates including, expansion ratio (ER), density (D), water absorption index (WAI), water solubility index (WSI) and hardness (H). Analysis of variance showed that the most significant variables are soybean residue, which has negative effect on ER and positive effect on H, and screw speed, which has positive effect on ER and H, while feed moisture is non-significant in most characteristics.

1. Introduction

Soybean residue, also known as okara, is food processing by-product of soya milk or tofu production process. For every 1 kg of dry soybean seed can produce approximately 2.5 kg fresh soybean residue with over 80% moisture content [1]. The amount of soybean residue, was produced annually, lead to significant extermination problem, most of it is dumped and burned as waste [2] although it is a good source of nutrients especially in protein content. Hence using soybean residue as human food is possible. However, raw soybean residue is undesirable due to the presence of enzyme inhibitors and unsavory 'fishy' and 'beany' flavor. Therefore, soybean residue had to be heat-treated before incorporating into various food products [3], such as noodle, bread, rice noodle, cake etc.

Extrusion-cooking technology is an economical and widely prevalent food processing method that involves mixing, cooking and forming process at short time and high temperature. The advantages of extrusion process are its high productivity, low cost, continuous production, short time, unique product and versatility [4]. In order to enhance nutrients in starch-based extrudate snack, vegetable and fruit by-products can be added. Generally, the raw materials used in starch-based product are corn, rice, wheat and potato [5, 6]. Some investigations intended to add vegetable or fruit by-products to improve extruded snacks such as brew's processing by-product [7], defatted soybean meal, mango peel fiber



[8] and fruit wastes [9]. Moreover, during extrusion process starch, protein and cellulose polymer transformation can be accomplished [4, 5] and extrusion process can modify the composition of soybean residue [3] by breaking enzyme inhibitor and allergen, and improving fiber content with accelerating depolymerization of glucosidic bonds [4, 6]. Therefore, the objective of this research is to study the effect of extrusion variables including screw speed, soybean residue and feed moisture on the characteristics of extrudate from corn based enriched with soybean residue including expansion ratio, density, WAI, WSI and hardness.

2. Materials and methods

2.1. Materials

Fresh soybean residue was supplied by soya milk vendor in Thanyaburi, Pathum Thani, Thailand. The fresh soybean residue (89.39% w/w in MC) was dried at 60°C in tray drier [modified 1], ground with hammer mill and stored at room temperature. Corn grit (mesh no. 3) was obtained from THAI MAIZE PRODUCTS CO., LTD., Bangkok, Thailand.

2.2 Extrusion experiments

Soybean residue (SR) was mixed with corn grit at 20%, 30% and 40% by weight and extruded with single-screw extruder. The screw L/D was 9:1. The screw speed was adjusted to 370, 400 and 430 rpm, while the extrusion temperature was fixed at 100°C. The feed moisture was set at 14%, 16% and 18%. The extrudate was then dried in a tray drier at temperature of 80°C for 10 minutes, then packed in polypropylene (PP) plastic bag and stored at room temperature until analyzed.

2.3 Analytical methods

2.3.1 Expansion ratio (ER). The expansion ratio was determined by measuring the diameter of extrudate by vernier caliper. 10 samples of extrudate were done randomly. Expansion ratio was calculated [10].

2.3.2 Density (D). Extrudates were cut into specific length of 4 cm and 10 sample of extrudate were randomly weighted, measured their actual geometric diameter and length. Density was calculated [10].

2.3.3 Water absorption index (WAI) and water solubility index (WSI). 2.5 grams of ground sample was dissolved in 30 mL of distilled water, stirred, and then centrifuged at 3000 rpm for 15 minutes. The supernatant was separated and dried on hot plate, then dried at 105°C in hot air oven until constant weight [11]. The WAI and WSI were calculated by the equations

$$WAI = \frac{\text{mass of wet pellet (g)}}{\text{dry sample (g)}} \quad (1)$$

$$WSI(\%) = \frac{\text{supernatant in dry solid (g)}}{\text{dry sample (g)}} \times 100 \quad (2)$$

The WAI and WSI were done in triplicate.

2.3.4 Hardness (H). Hardness, defined as a maximum peak force, is examined by TA.XT.plus texture analyzer equipped with P/2 cylindrical probe. The tests were carried out at a pre-test speed: 1.0 mm/s; test speed: 1.0 mm/s; post-test speed: 10.0 mm/s; distance: 12 mm [11].

2.4 Statistical analysis

Experimental design was performed using a three-level, three-factorial Box-Behnken design (BBD) of Response Surface Methodology (RSM) [7] by Design-Expert software version 11. The three independent variables included screw speed (X_1 , rpm), soybean residue (X_2 , %) and feed moisture (X_3 , %). A total number of 17 experiments were run with five replicates of the central point. Regression

analysis was performed to generate a response surface model. A second order polynomial model (equation 3) was examined for its fit to describe the response surface and R^2 were estimated.

$$Y = \beta_0 + \sum_{i=1}^3 \beta_i X_i + \sum_{i=1}^3 \beta_{ii} X_i^2 + \sum_{i=1}^2 \sum_{j=i+1}^3 \beta_{ij} X_i X_j \quad (3)$$

where Y are ER, D, WAI, WSI, and H, β_0 , β_{ii} and β_{ij} are constant coefficient and X_1 , X_2 and X_3 are coded independent variables. The fits of all models were determined using ANOVA. F-value at probability ($p < 0.05$) confirming the significance of the models [10].

3. Results and discussion

Fresh soybean residue contains 89.39% moisture After drying at 60°C with tray drier and grinding, dried soybean residue consists of 12.68% moisture and 22.56% protein, whereas corn grit consists of 6.75% moisture and 6.45% protein. The protein content of extrudates varied from 9.67 to 12.89%. The effects of three different levels of extrusion variables on extrudate characteristics were evaluated.

3.1 Expansion ratio (ER) and Density (D)

Breakfast cereal and second generation snacks were expanded directly from die. The expansion ratio (ER) indicates the quality of puffing of the extrudate. [6, 5] The ER values ranged between 2.73 to 1.75. Table 1 shows that the fitted model was non-linear. The linear effects of SR ($p < 0.00$) negatively affects ER, whilst screw speed ($p = 0.01$) and FM ($p = 0.05$) positively affect ER. Fig. 1a shows that at a given FM of 16%, ER decreased with SR increases as SS changed from 370 to 430 rpm. Because of the presence of fiber in SR in product, the flashing off steam, which leads to expanded product, is prevented [10]. Many results were observed for addition of fiber expansion ratio of extrudates decreased [5, 10, 11]. Besides, the studies had been reported that starch-protein interactions also had a negative effect on ER, while SS had a positive effect on ER [12, 13]. The FM decreased with the decrease of the ER of extruded products. Low moisture in the blend may cause poor superheated water, resulting in a decreased of ER [5].

The density (D) values varied from 0.212 to 0.460 g/cm³. Table 1 shows linear term of SR had a positive effect ($p < 0.00$) while SS ($p = 0.06$) had negative effect on D. The increase of SF from 20 to 40% increased D. Moreover, increase of SS decreased D at the same level of SR as represented in fig. 1b. It can be explained that the fiber tends to rupture cell walls before the air bubbles had

Table 1. Adequacy of model fitted

Parameter	Fitted models	R^2	p value	C.V. %
ER (cm/cm)	ER=2.15+0.113*X ₁ -0.343*X ₂ +0.083*X ₃ -0.014*X ₁ X ₂ -0.013*X ₁ X ₃ -0.045*X ₂ X ₃ -0.052*X ₁ ² +0.092*X ₂ ² -0.045*X ₃ ²	0.94	<0.00	4.68
D (g/cm ³)	D=0.327-0.025*X ₁ +0.076*X ₂ -0.01*X ₃ -0.017*X ₁ X ₂ -0.018*X ₁ X ₃ +0.009*X ₂ X ₃ +0.006*X ₁ ² -0.004*X ₂ ² -0.011*X ₃ ²	0.89	0.01	9.67
WAI (g/g)	WAI=6.26+0.092*X ₁ -0.337*X ₂ -0.014*X ₃ +0.117*X ₁ X ₂ -0.005*X ₁ X ₃ -0.215*X ₂ X ₃ -0.136*X ₁ ² -0.181*X ₂ ² -0.153*X ₃ ²	0.83	0.05	3.58
WSI (%)	WSI=13.62-0.154*X ₁ -1.07*X ₂ +2.83*X ₃ +0.335*X ₁ X ₂ +1.64*X ₁ X ₃ -2.80*X ₂ X ₃ -0.697*X ₁ ² -1.40*X ₂ ² +0.726*X ₃ ²	0.84	0.04	14.37
H (N)	H=26.10+2.49*X ₁ +3.29*X ₂ -2.49*X ₃ +4.61*X ₁ X ₂ +1.24*X ₁ X ₃ +2.32*X ₂ X ₃ +2.73*X ₁ ² -0.486*X ₂ ² -0.805*X ₃ ²	0.82	0.05	11.98

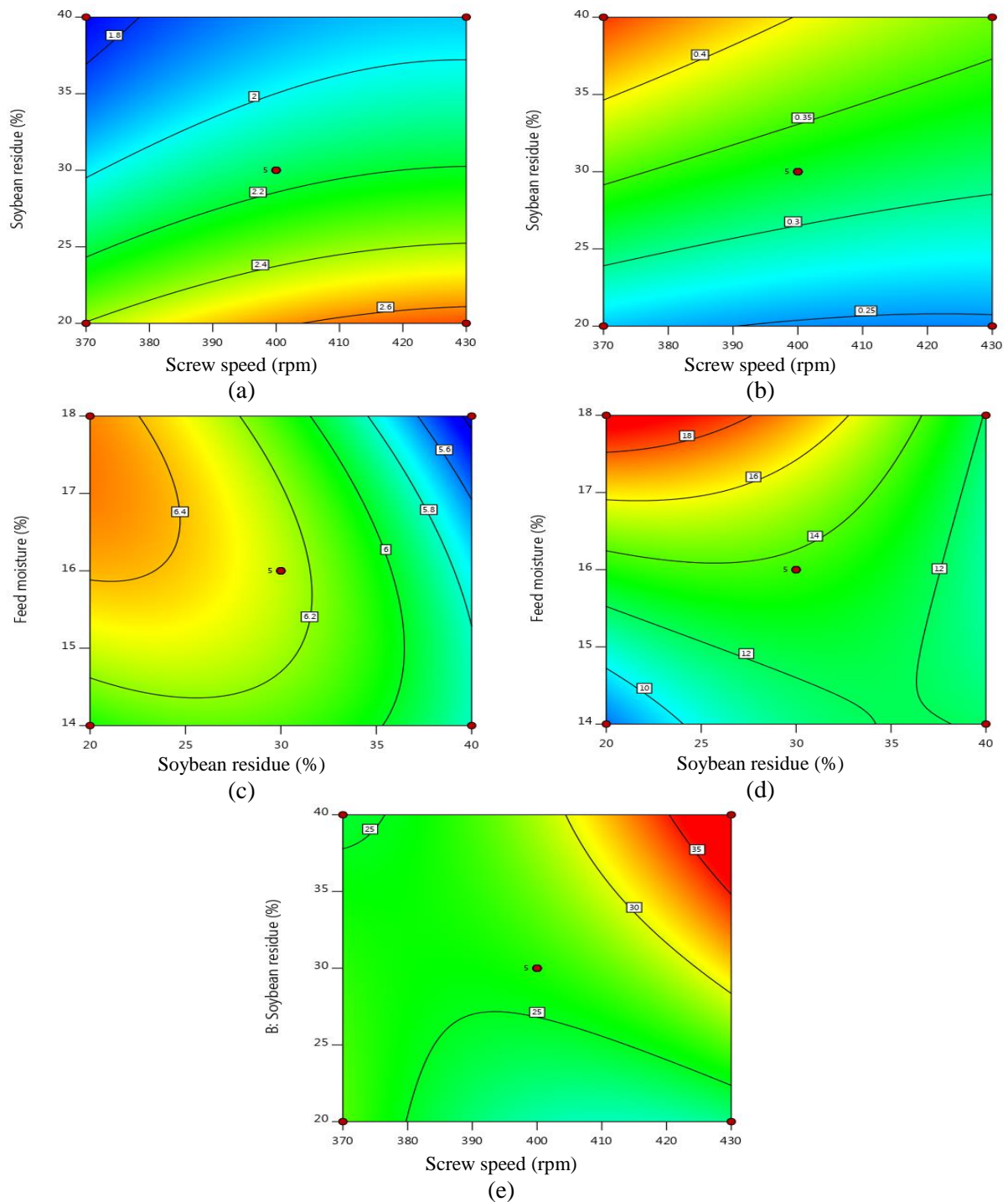


Fig.1. Effect of variables on (a) Expansion ratio (cm/cm), (b) Density (g/cm³), (c) WAI (g/g), (d) WSI (%), and (e) Hardness (N)

expanded, so the product maximum expanding was prevented. [11, 6]. The same results of effect of SS on D were observed [13]. The data indicates that D was negatively correlated with ER. Similar results were observed [14].

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

WAI and WSI are used to evaluate the functional characteristics of extruded products. WAI reflects the ability of starch to absorb water and serves as indicator of starch gelatinization [6]. Besides, improvement of WAI depends on protein denaturation at high feed moisture [15]. The WAI values of extrudates ranged from 6.62 to 5.46 g/g. The linear term of soybean residue ($p<0.00$) and interaction term of soybean residue and feed moisture ($p=0.08$) had negative effects on WAI (table 1). Fig. 1c suggests that the addition of FM and reduction of SR gives the highest value of WAI. The results indicate that the increase of SR, decreased the WAI values. It is could be due to undamaged long polymer chains in the gelatinized sample [7]. The reduction of starch in blend also reduces gelatinized starch, which lead to less water holding and decreased WAI [6]. The results are in agreement with previous work by [10, 11, 13].

WSI indicates the amount of soluble molecules released from starch and degradation of molecular components, and is also related to dextrinization [6]. The highest value of WSI was 19.00% WSI and the lowest value was 7.07% WSI. Linear term of the FM ($p<0.00$) and interaction term of SR and FM ($p=0.02$) were responsible for WSI values (table 1). The effect of linear terms on WSI values is represented in fig. 1d. The result clearly shows that WSI increased with FM. In contrary, the studies had been reported that low FM causes an increase of WSI value due to the amount of degraded starch and other components were risen [10,]. In this study, WSI increased with the FM probably due to complete starch gelatinization and protein denaturation from native food components [15]. Furthermore, high FM could also lead to proper gelatinization of starch, resulting in increasing WSI [16]. Additionally, WSI has a negative correlation with WAI [6].

3.3 Hardness (H)

Hardness (H) is the maximum peak obtained from measuring of extruded products [10]. Hardness of extrudates ranged from 15.63 N to 35.44 N. The content of SR ($p<0.02$) and interaction effect of SS and SR ($p=0.02$) positively affected hardness (table 1). Fig. 1e shows that highest value of hardness was processed at 40% SR and 400 rpm SS at a given 16% FM. This may be explained that the presence of cell wall in the fiber of SR can cause increases in hardness of extrudate [5]. Similar result was observed by [7]. Besides, high protein portion of raw material increases hardness as well [17].

4. Conclusions

The result showed that soybean residue and screw speed significantly affected extrudate characteristics. Soybean residue had importantly effect to expansion ratio, water absorption index, water solubility index and hardness, while screw speed had importantly effect to expansion ration, density and hardness.

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