J Food Sci Technol (September 2018) 55(9):3462–3472
https://doi.org/10.1007/s13197-018-3271-2

ORIGINAL ARTICLE

Influence of process parameters on physical properties and specific mechanical energy of healthy mushroom-rice snacks and optimization of extrusion process parameters using response surface methodology

Hataichanok Kantrong[1] · Chulaluck Charunuch[1] · Nipat Limsangouan[1] · Worapol Pengpinit[1]

Revised: 16 May 2018 / Accepted: 28 May 2018 / Published online: 19 June 2018

Abstract Ready-to-eat healthy mushroom-rice snacks were developed and processed using twin-screw extruder. A 15% of oyster mushroom power could be added to improve the nutritional values of the rice based snack. The effects of process parameters (feed moisture, screw speed and barrel temperature) on physical properties and Specific Mechanical Energy (SME) during the production were investigated. Feed moisture was varied at 12–18% wet basis and the screw speed was studied in the range of 275–425 rpm, while the barrel temperature was operated at 130–150 °C. The result indicated that bulk density differed significantly with changes in all the process parameters. An increasing barrel temperature caused higher expansion ratio, while hardness of snacks increased due to an increase of feed moisture and a decrease of screw speed. SME was considered by measuring the electric current and voltage of the extruder. As a result, feed moisture demonstrated the most influence on the SME. Feed moisture between 12 and 15% wet basis, the SME decreased with decrease in feed moisture. On the other hand, the SME decreased when the higher feed moisture was operated in the range of 15–18% wet basis. In addition, the process condition was optimized using response surface methodology. From this study, the optimum extrusion-cooking conditions with respect to the physical qualities of snacks and SME during extrusion was 13.5% of feed moisture, screw speed of 425 rpm and maximum barrel temperature at 130 °C, since these conditions provided a good quality mushroom-rice snacks and consumed low SME.

Keywords Extrusion process · Mushroom-rice snack · Specific mechanical energy (SME)

✉ Hataichanok Kantrong
hataichanok.kan@ku.th

[1] Institute of Food Research and Product Development, Kasetsart University, P.O. Box 1043, Kasetsart, Bangkok 10903, Thailand

Introduction

Recently, ready-to-eat snack foods become an integral part of the eating habits of the majority of world's population due to their convenience, wide availability, appearance, taste and texture. Generally, the major ingredient in snack formula is starch and the most common sources of ingredients are corn, wheat, potato and rice. Therefore, snack is classified as a junk food because it is produced from starchy raw materials containing low protein, fiber and low in nutritional value. Thus, development of healthy snack is needed in order to satisfy the market demand of healthier food products. To improve the nutritional quality snacks, various sources of fiber, protein and agricultural products rich in nutritional benefits have been added. Some other agricultural products are also added into snack to increase their health benefits such as radish (Gupta and Premavalli 2012), chestnut mushroom (Brennan et al. 2012), banana (Kaur et al. 2015), yam (Seth et al. 2015), kidney bean (Agathian et al. 2015), carrot (Alam et al. 2016), cauliflower (Alam et al. 2016), mango (Salgado et al. 2017) and mung bean (Sharma et al. 2017).

This work aims to add the oyster mushroom into the snack formula in order to increase its health benefits. Oyster mushroom contains low calories and fat (1.59%), on the other hand rich in protein (30.18% crude protein), fiber (3.56%), vitamins, and minerals (Piamvaree et al. 2011). Besides, broken jasmine rice is also used as a main raw material not only because it has high starch content, excellent expansion properties, but also to increase its value. Moreover, soybean flour is also added in order to increase protein content in this product. Thus far, there have been limited reports of developing healthy mushroom-rice snack by adding the oyster mushroom powder in the formula.

As we know, extrusion process can be used to produce various kinds of ready-to-eat food products such as breakfast cereal, instant cereal drink and snack (Agathian et al. 2015). During the extrusion process, raw materials will be processed under high temperature, short time (HTST), high absolute pressure and high shear force. The characteristics of the extruded snacks depend on the chemical content, rheological and physical properties of the raw materials, as well as the operating conditions. The works of Guerrero et al. (2012), Charunuch et al. (2014), Awolu et al. (2015), Kaur et al. (2015) and Alam et al. (2016) showed that the three most important parameters of the extrusion process were feed moisture or the moisture of mixed material feeding into the extruder, screw speed and the temperature of the extruder barrel.

In a typical extrusion operation, the qualities of the products are normally concerned as the first priority factors. However, in an engineering point of view, Specific Mechanical Energy is an important factor for designing and it should be concerned in parallel with the quality for productivity of the process. Specific mechanical energy (SME) is defined as the amount of work input from driver motor into the raw material being extruded and is produced as a result of the friction generated between the screw and the product. Thus, it provides a good characterization of the extrusion process. Process parameters that greatly affect the SME are moisture of the raw materials, screw speed, barrel temperature and raw material properties. Therefore, an understanding of the relationships among extrusion process parameters, SME and the properties of the materials is necessary for the extrusion process because SME could help to determine an optimum process condition which will provide good quality of the products and energy efficiency, as well as explain the mechanism (Tremaine 2012).

Therefore, this research aimed to investigate the effect of process parameters: feed moisture, screw speed and barrel temperature on the physical properties of extruded oyster mushroom-rice snack including SME during extrusion process. Moreover, response surface methodology (RSM) was applied to optimize production of extrude oyster mushroom-rice snack. The optimization conditions and the verification results obtained from this research will determine the optimum levels of feed moisture, screw speed and maximum barrel temperature for producing snack with low SME, while still providing good physical properties of the product.

Materials and methods

Preparation of dried oyster mushroom

The oyster mushroom purchased from the farm in Nonthaburi province was washed in tab water at room temperature and cut into small pieces (thickness about 0.5 cm). After that, it was blanched in boiling water containg 0.5% citric acid for 1 min followed by draining and drying in hot air dryer at 70 °C for 3 h and at 60 °C for 6 h (Martínez-Soto et al. 2001; Piamvaree et al. 2011). The average final moisture content of dried oyster mushroom was 6.44% wet basis.

Preparation of raw materials

Raw materials used in this work consisted of dried oyster mushroom (15%), broken jasmine rice (60.5%), soy bean flour (18%), vegetable oil (1%), $CaCO_3$ (0.5%) and modified starch (5%). Before mixing, dried oyster mushroom and broken Jasmine rice were ground using Fitz mill (Model M5, USA.) with 60 mesh screen. After that, the ingredients were weighed according to the above proportions and then mixed homogenously using a mixer (KitchenAid, USA). The initial moisture content of the mixed ingredient was measured by a moisture balance (A&D, Model MX-50, USA).

Extrusion process

The homogenous mixed ingredient was extruded by an intermeshing co-rotating twin screw extruder (Hermann Berstorff Laboratory, ZE25 × 33D, Hannover, Germany) with the length/diameter ratio of 870:25. This extruder consisted of 7 barrel parts ending with a 24.5 mm thick die plate with one 3.5 mm circular hole. The raw material feeding system (K-Tron soder AG 5702, type 20; Niederlenz, Switzerland) was connected to the extruder and maintained the solid feed rate at 17 kg/h. The extruder was operated at 3 levels of feed moisture (12, 15 and 18% wet basis), 3 levels of screw speed (275, 350 and 425 rpm.) and 3 levels of maximum barrel temperature or temperature of barrel No. 6 (130, 140 and 150 °C). After the extrusion process reached a steady-state condition (no visible drifts in electric current; amp of the controller), the sample was then collected and dried in a hot air dryer at 80 °C for 15 min in order to reduce the moisture content to less than 5% wet basis. Then it was cooled to room temperature and packed in polyethylene bags for further analysis of its physical properties.

Quality evaluation

Bulk density

The bulk density of each snack treatments was measured by gently placing the extruded product to fill a 1000 ml cylinder, after that the bulk density was calculated as weight of the product (g) divided by the volume of the cylinder (ml).

Expansion ratio

To calculate the expansion ratio, vernia caliper was used to measure the diameter of the extrudate and a diameter of a die hole. Expansion ratio is the ratio of the diameter of the extrudate to the diameter of the die hole.

Textural properties

Textural properties in terms of hardness and crispness were analyzed using Texture Analyzer (Model TA-XT2i, Stable Micro System, England). Snack samples were punctured by the probe at a speed of 2.0 mm/s to a distance corresponding to approximately 30% of the height of the extrudates. The blade set and Warner–Bratzler: HDP/BSW probe was used to measure the textural properties of the snacks. The results of hardness and crispness were calculated from a force–time curve of the test. Hardness obtained from the maximum peak force of the curve and crispiness is the number of peaks during fracture. The measurements were taken ten times and the reported results were the mean values.

Specific mechanical energy (SME)

Specific mechanical energy represents the total mechanical energy that is used to drive the extruder motor during the process per 1 kg of the raw materials. It can be determined from the electric current and the voltage of the extruder expressed as the following equation (Feng and Lee 2014):

$$\text{SME (kJ/kg)} = \frac{\text{loading power(kJ/s)} - \text{empty power (kJ/s)}}{\text{feed rate (kg/s)}}$$

$$\text{SME} = \frac{(\text{Amp} \times \text{Volt})_{\text{with load}} - (\text{Amp} \times \text{Volt})_{\text{with no load}}}{\text{feed rate}}$$

where Amp is the electric current reading from the control panel of the extruder. Volt is the voltage reading from the control panel of the extruder.

Experimental design and statistical analysis

A three-factor, three-level Box–Behnken design and response surface methodology (RSM) were employed to investigate the effects of process parameters on the physical properties of the healthy mushroom-rice snacks, including SME study. The main independent factors were the feed moisture (X_1), the screw speed (X_2) and the barrel temperature (X_3). The experimental design composed of 15 runs and the three levels of the process parameters (low, intermediate and high, being coded as − 1, 0 and + 1) were settled based on the preliminary experiment as shown in Table 1. The responses were expansion ratio, bulk density, textural properties and SME. Moreover, RSM was also utilized to optimize the process conditions, in order to obtain the high quality product utilizing low energy or SME. To quantify the relationships between dependent variables and independent variables, regression analysis was based on the test results from the experimental design. The regression model between dependent variable (Y) and independent variables (X) can be generally written as:

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

where Y was the response variables; β_0, β_i, β_{ii}, and β_{ij} were the regression coefficients of variables for intercept, linear, quadratic and interaction terms, respectively; and X_i and X_j were independent variables. The Box–Behnken design and statistical analysis were carried out using MINITAB version 15 statistical software packages.

For the optimization procedure, the regression model adequacies were checked in terms of no significant lack of fit and high R^2. Optimum process conditions can be determined from the overlaid graph of the response contour plots to obtain a good physical appearance of the product and utilize low SME. Finally, verification of optimized conditions and predicted values were performed to confirm the validity of the regression models.

Results and discussion

The effects of the process parameters on the physical properties of oyster mushroom-rice snack and SME during the extrusion process were investigated. The significant levels of the regression models and coefficient of each term in the regression models are shown in Table 2.

The R^2 for each of responses were higher than 0.75 referred to the good correlations among the process parameters, physical properties and SME. In addition, the lack of fit were no significant ($p > 0.05$), indicating that the second-order polynomial models correlated well with the

Table 1 Box–Behnken design for the experimental study

Run no.	Coded values			Uncoded values		
	X_1	X_2	X_3	Feed moisture (% wet basis)	Screw speed (rpm)	Temperature of barrel (°C)
1	− 1	− 1	0	12	275	140
2	1	− 1	0	18	275	140
3	− 1	1	0	12	425	140
4	1	1	0	18	425	140
5	− 1	0	− 1	12	350	130
6	1	0	− 1	18	350	130
7	− 1	0	1	12	350	150
8	1	0	1	18	350	150
9	0	− 1	− 1	15	275	130
10	0	1	− 1	15	425	130
11	0	− 1	1	15	275	150
12	0	1	1	15	425	150
13	0	0	0	15	350	140
14	0	0	0	15	350	140
15	0	0	0	15	350	140

X_1 is feed moisture, X_2 is screw speed and X_3 is temperature of barrel no. 6

Table 2 The regression coefficient of responses and the coefficients of determination (R^2) calculated on coded values

Variables	Expansion ratio	Bulk density (kg/m^3)	Hardness (g)	Crispness	SME (kJ/kg)
Constant	2.817**	92.117**	1429.03**	20.867**	402.536**
X_1	0.044	22.221**	416.64**	− 0.925	22.769
X_2	0.064	− 16.754**	− 239.45*	1.375	0.081
X_3	0.075*	− 12.885**	− 130.45	1.050	23.683
X_1X_1	− 0.086	20.350**	288.21	− 4.433*	− 89.269*
X_2X_2	0.114*	4.960**	90.96	1.267	− 42.194
X_3X_3	0.157**	− 5.977**	99.92	0.717	1.868
X_1X_2	− 0.015	− 3.852**	103.46	0.300	− 6.700
X_1X_3	− 0.032	− 14.585**	− 104.38	− 1.750	− 17.117
X_2X_3	− 0.017	− 0.185	67.92	2.350	− 27.968
F-value					
Regression	5.87*	352.74*	4.01	2.39	1.75
Linear	6.06*	778.11*	9.81*	1.46	0.95
Square	11.14*	185.97*	1.70	4.06	3.81
Interaction	0.41	94.15*	0.52	1.65	0.49
R square (%)	91.4	99.8	87.8	81.1	75.9
Lack-of-fit	0.405^{ns}	0.103^{ns}	0.110^{ns}	0.352^{ns}	0.466^{ns}

*Significant at $p < 0.05$

**Significant at $p < 0.01$

^{ns}Not significant

X_1 is feed moisture, X_2 is screw speed and X_3 is temperature of barrel no. 6

measured data. Hence it can be applied to optimize the extrusion process of oyster mushroom-rice snack.

Effects of process parameters on expansion ratio and bulk density of extruded mushroom-rice snack

Table 2 clearly shows significant ($p < 0.05$) regression model for expansion ratio with the high coefficient of determination ($R^2 = 0.914$) and F-value for the lack of fit was no significant thereby confirming the validity of the model. Only the barrel temperature showed a significant effect on expansion ratio ($p < 0.05$) whereas all the process parameters exhibited a strong significant effect on the bulk density ($p < 0.01$). The regression analysis in Table 2 revealed that the regression model for bulk density was significant ($p < 0.05$). The coefficient of determination being high ($R^2 = 0.998$) and no significant lack of fit. The expansion ratio of mushroom-rice snack is in the range of 2.66–3.16 as can be seen in Fig. 1a, b. While, the bulk density value of the snack is between 61.76 and 161.62 kg/m^3, whose contour plots of the relationship between the process parameters and the bulk density is as shown in Fig. 1c, d. In general, the bulk density of snacks represents the porosity of the product (Omwamba and Mahungu 2014) varying according to the raw materials properties and the process parameters.

The expansion ratio of the mushroom-rice snack increased when the higher extruder barrel temperature was operated. Similar effect of barrel temperature on expansion was found in the work of Charunuch et al. (2014), Kaur et al. (2015) and Alam et al. (2016). The expansion ratio was significantly increased as the temperature was increased. The increment of expansion ratio with operating temperature was attributed to its higher degree of gelatinization. Moreover, operating the extruder under the high temperature caused the moisture in the sample to superheat. When the dough left at the exit of the die, the sudden pressure drop caused the moisture to rapidly evaporate which led to the formation of bubbles and resulting in the expansion of the product. A converse relationship between extrusion temperature and expansion ratio was reported by Thakur et al. (2017). Expansion ratio of extruded corn grit significantly decreased with increasing of extrusion temperature. This indicated that the effect of higher extrusion temperature might be positive or negative to the expansion characteristic depending on the compositions and rheological properties of the input materials (Altan and Maskan 2012).

In the case of the bulk density, this value increased with increasing feed moisture but it decreased with higher screw speed and barrel temperature. This is because, operating an extruder at higher temperature will increase the degree of superheating of water within the extruder barrel which helps to increase bubble formation and decrease in melt viscosity as well. This leads to reduction of bulk density and increasing of expansion ratio of the mushroom-rice snack (Altan and Maskan 2012; Omwamba and Mahungu 2014; Singh and Muthukumarappan 2016; Alam et al. 2016). Besides, with increasing screw speed, higher absolute pressure inside the barrel will develop. When dough exits through the die exit, the pressure inside the product rapidly drops resulting in more water evaporation, which will lead to greater expansion ratio and reduction of bulk density of the extrudate (Chevanan et al. 2008; Seth et al. 2015; Kaur et al. 2015). In addition, an increasing screw speed at the constant feed moisture results in a higher shear force and rubbing action. This helps to uniform the moisture distribution causing a decrease in melt viscosity, thus increasing expansion ratio (Altan and Maskan 2012; Min et al. 2015). Contour plots of the effect of feed moisture on bulk density are shown in Fig. 1c, d. It was found that bulk density increased as feed moisture increased. This is due to the fact that an increase in feed moisture lowers its viscosity leading to the collapse of the bubbles inside the extrudate after expansion at the die exit, thus resulting in an increase in bulk density (Altan and Maskan 2012). The effects of feed moisture, screw speed and barrel temperature on bulk density was also investigated in the development of a protein-rich snack from a composite blend of rice, sorghum and soybean flour (Omwamba and Mahungu 2014). It was found that the bulk density of snack was significantly affected by the barrel temperature and moisture content but screw speed had no significant effect on the bulk density.

Effects of process parameters on textural properties of mushroom-rice snack in terms of hardness and crispness

Textural properties of food are one of the most important parameter affecting to consumers' purchasing decision. Texture of good quality snack should be crispy with low product hardness. In this work, the mushroom-rice snack texture was described using the attributes of hardness and crispness. Hardness is defined as the force applied by the molar teeth to compress the food while, crispiness represents the noise of food during mastication (Paula and Conti-Silva 2014).

The effects of process parameters on hardness of mushroom-rice snack are shown in Fig. 1e, f. Hardness of mushroom-rice snack is in the range of 1177.28–2600 g. The hardness values found in this work were higher than the hardness of extruded snack enriched with coproducts from chestnuts mushroom reported by Brennan et al. (2012). Some studies have shown higher results (Gat and Ananthanarayan 2015; Alam et al. 2016) or lower values

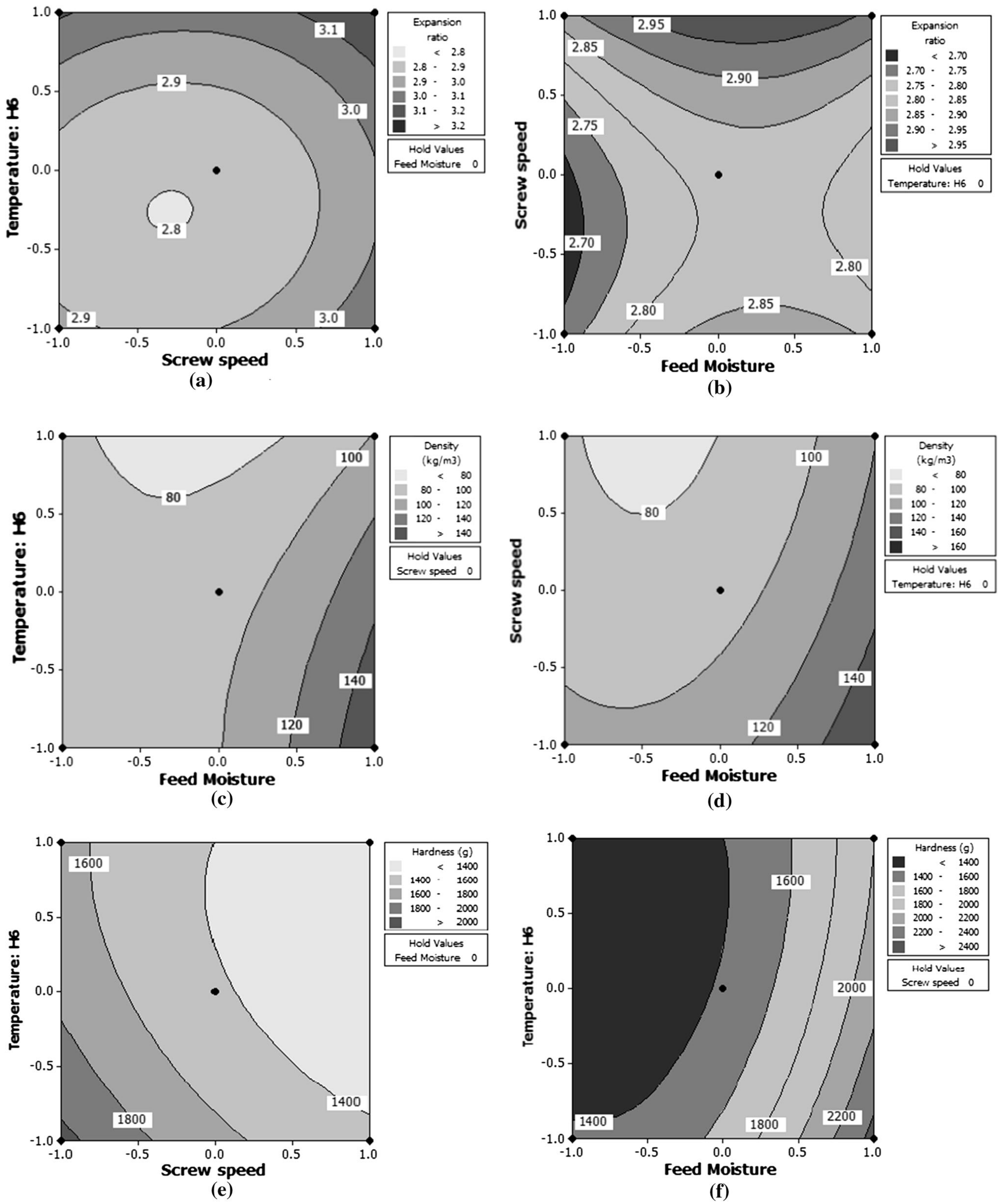

Fig. 1 Effects of process parameters on physical properties of extruded mushroom-rice snack in terms of expansion ratio (**a**, **b**), bulk density (**c**, **d**) and hardness (**e**, **f**)

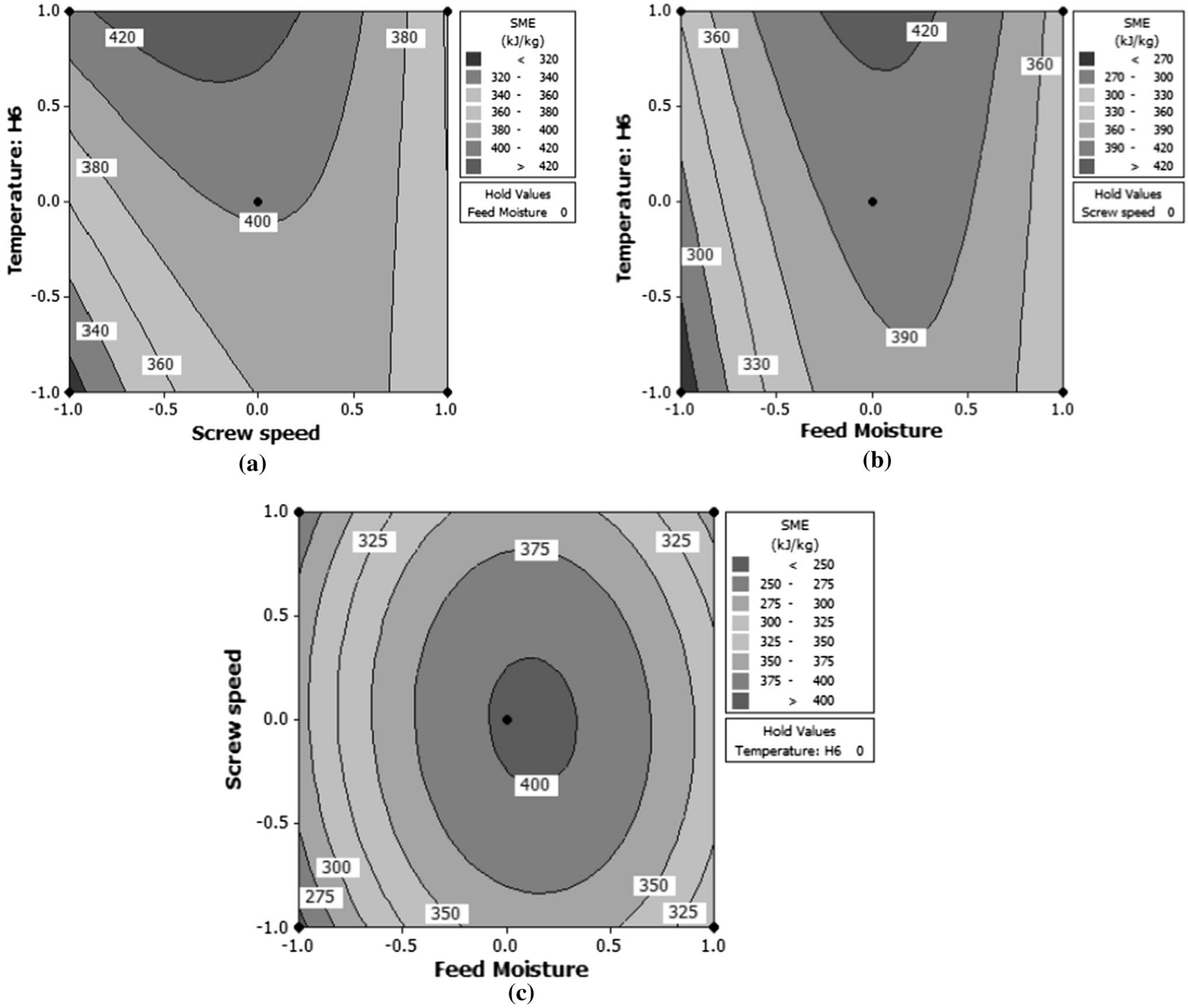

Fig. 2 Effects of process parameters on SME of extruded mushroom-rice snack

(Gupta and Premavalli 2012; Seth et al. 2015) compared to present study. This is because the different probes, method applied and snack formula resulted in different cut force in the test. Table 2 indicated that the regression model of hardness had high R^2 (0.878) and non significant F value showing the adequacy of model to the experimental data. Statistical analysis in Table 2 revealed that the feed moisture and screw speed demonstrated significant effect on hardness ($p < 0.05$).

Contour plot in Fig. 1f indicated that hardness of mushroom-rice snack increased with the increase of feed moisture of the materials that flowed in the extruder while the hardness of the snack tended to be increased when the extruder was operated at the low temperature as can be seen in Fig. 1e. However, hardness of snack will be decreased when the higher screw speed was operated as shown in Fig. 1e. As described above, higher feed moisture caused less expansion ratio, hence the snack gained more compact texture leading to higher hardness value. This is because the more water in the materials will act as lubricant in the screw, thus reducing shear force and friction between food material and screw of extruder. This result was in agreement with the researches of Gat and Ananthanarayan (2015) and Salgado et al. (2017). Extrusion under lower extruder barrel temperature may reduce the starch gelatinization, resulting in decreasing of the expansion and increasing the density of extrudate. Similar results have been reported by Ding et al. (2006), Stojceska et al. (2009) and Hood-Niefer and Tyler (2010). In the case of screw speed, the higher screw speed caused higher shear force and absolute pressure inside the barrel, therefore leading to higher porosity inside the extrudate resulting in decreasing hardness (Min et al. 2015).

Crispness is one of the key sensory attribute that reflects consumers' acceptance. It can be measured by counting the number of peak produced as a result of the fracture of the mushroom-rice snacks that has occurred during the testing. The results from texture analyzer found that crispness of mushroom-rice snack is in the range of 14.6–29.6. The regression coefficients of crispness are presented in Table 2. The results showed that the R^2 was 0.811 and F value of lack of fit was no significant suggesting good fit of the regression model. In addition, statistical analysis revealed that square term of feed moisture exhibited a significant effect to the crispness ($p < 0.05$).

The crispness of mushroom-rice snack was increased when the higher screw speed and higher extruder barrel temperature were applied. This was due to the higher screw speed and barrel temperature caused an increase in shear force and absolute pressure, thus moisture rapidly evaporated causing more production of bubbles, as a result samples gained crispy texture. This finding agreed well with the work of Min et al. (2015). Comparing between the mathematical model of hardness and crispness, it was found that hardness showed inverse relationship to crispness. Increasing the feed moisture increased the hardness whereas decreased crispness.

Effects of process parameters on SME

SME is a function of many parameters such as moisture content of the material, screw speed viscosity of the material and so on. The results of SME from this work are in the range of 198.69–416.11 kJ/kg. The values of SME reported in this work were lower than those reported for

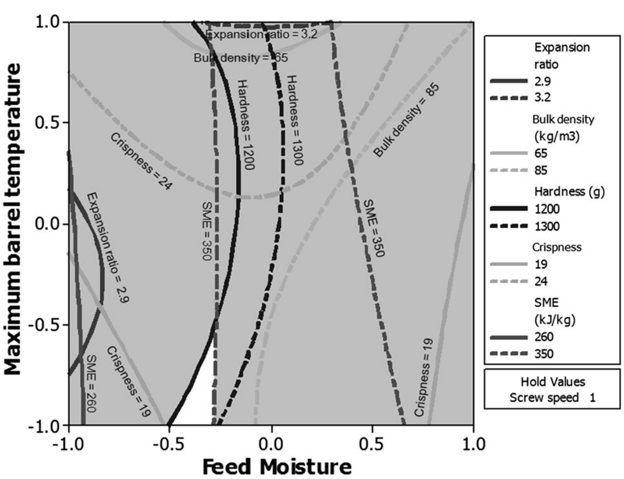

Fig. 3 Optimum region identified by the overlaid contour plots of the responses at different levels of feed moisture and temperature while holding optimal screw speed

green gram-rice extrudate (650–1250 kJ/kg) and extrusion of fura from pearl millet and bambara groundnut (380.5–765.8 kJ/kg) (Chakraborty and Banerjee 2009; Filli et al. 2012), probably due to the higher level of protein in the formula compared to this study. Hence, it contribute to higher dough viscosity, thus the higher SME is required. Furthermore, it has been documented that the efficient of SME for the extrusion process must be lower than 1000 kJ/kg (Camacho-Hernández et al. 2014). The coefficient of determination (Table 2) was moderately high ($R^2 = 0.759$) and F-value for the lack of fit was no significant, indicating that the experimental values were in good agreement with the predicted values. In addition, Table 2 indicated that the squared term of feed moisture demonstrated significant effect to SME ($P < 0.05$). SME will increase when the feed moisture reaches one point and then will decrease when feed moisture increases as can be seen in Fig. 2.

According to the results presented in Fig. 2, the highest SME was obtained at the middle level of both feed moisture and screw speed and under high level of extruder barrel temperature. This is because operating an extruder under high extruder barrel temperature generally leads to a decrease in dough apparent viscosity, which results in lower in SME (Muthukumarappan and Karunanithy 2012). From Fig. 2a, c, SME increases when the higher screw speed is operated in the range from 275 to 300 rpm. This can be attributed to the fact that higher screw speed resulted in an increase of shear force act to the food material, and consequently leading to a higher friction force between material and wall of extruder barrel (Akdogan 1996; Chang et al. 1999; Filli et al. 2012). On the other hand, operating of extruder in the higher screw speed range from 350 to 425 rpm leads to lower SME. As screw speed increases, dough viscosity decreases due to gaining non-Newtonian behavior after facing with higher shear force (Muthukumarappan and Karunanithy 2012). Similar effect of screw speed on SME was found in the work of Chakraborty and Banerjee (2009). Moreover, the type of material and screw configuration also affected SME, however the most important process parameter affecting SME is feed moisture of the material. It does not only affect the SME but also pressure inside the extruder barrel and strain applied to the extrudates, resulting in differences in a product's characteristics (Altan and Maskan 2012). In Fig. 2b, c the feed moisture in a range of 12–15% wet basis indicated that the lower feed moisture resulted in a decrease of SME, possibly coming from the presence of vegetable oil in the formula. In general, addition of 0.5% vegetable oil in the raw materials could reduce SME (Janes 1993), especially in the low feed moisture raw materials at a constant other process parameters (Muthukumarappan and Karunanithy 2012). As for the feed moisture in a range of 15–18% wet basis, SME will decrease with the higher

Table 3 Actual and predicted values of selected response tested under selected conditions for verification of the optimized region

Optimum point	Feed moisture (%)	Screw speed (rpm)	Temperature of barrel no. 6 (°C)	Expansion ratio		Bulk density (kg/m^3)		Hardness (g)		Crispness		SME (kJ/kg)	
				Predicted	Actual	Predicted	Actual	Predicted	Actual	Predicted	Actual	Predicted	Actual
1	14	425	130	3.06	3.09 ± 0.05^{ns}	79	79 ± 1.75^{ns}	1267	1249 157.83^{ns}	20	23 ± 4^{ns}	345.65	344 ± 17.32^{ns}
2	14	425	130	3.04	3.06 ± 0.06^{ns}	76	77 ± 0.95^{ns}	1202.81	1219 106.11^{ns}	19	23 ± 7^{ns}	327.69	326 ± 5.43^{ns}

^{ns}Not significant for *t* test at 95% level confidence

feed moisture. This may be due to the combination effect of both vegetable oil and water which will reduce the viscosity of the dough in the extruder barrel, causing the decrease in shear rate and torque. In this experiment, the increase in feed moisture in the range of 15–18% could reduce SME. This finding is consistent with the works of Bhattacharya and Hanna (1987), Altan and Maskan (2012) and Sharma et al. (2017).

Optimization of extrusion process condition for mushroom-rice snack

Process optimization was carried out by superposition of several contour surface of selecting responses. The expansion ratio, bulk density, hardness, crispness and SME were selected as the responses to optimize the process parameters (feed moisture, barrel temperature and screw speed). The main criteria for determining the optimum overlaid area were the high expansion ratio, low bulk density, equivalent to or better textural properties than commercial snack and the lowest consumption of SME. The minimum–maximum limits of responses' criteria were bulk density (kg/m^3) = 65–85, expansion ratio = 2.9–3.2, hardness (g) = 1200–1300, crispness = 19–24 and SME (kJ/kg) = 260–350.

The overlaid area corresponding to the optimal conditions for desirable or best product quality is shown in Fig. 3. The white area indicated the range of variables which could be considered as the optimum condition which provided good quality of the product and consumed low SME.

Verification

The verification of extrusion process was carried out using optimum conditions from the white region in the overlaid graph and all the responses: expansion ratio, bulk density, hardness, crispness and SME were analyzed, then compared with the predicted values as expressed in Table 3. From the results, it was found that the actual values obtained from the verification experiment were not significantly different from the predicted values for both extrusion conditions at 95% confidence level. This indicated that the mathematical model was adequate for predicting optimum conditions in healthy mushroom-rice snack production.

Conclusion

Ready-to-eat healthy snack from blend of oyster mushroom, jasmine rice and soybean flour were obtained by twin screw extrusion. Box–Behnken design was successfully utilized to design the experiment and evaluate the effects of process parameters: feed moisture (12–18% wet basis), screw speed (275–425 rpm) and barrel temperature (130–150 °C) on the physical properties of extruded mushroom-rice snacks, SME was also studied as well. All the process parameters strongly affected the bulk density of mushroom-rice snacks. An increased barrel temperature resulted in an increase in expansion ratio. In addition, hardness of snacks increased with higher feed moisture and lower screw speed. The process parameter having the most influence on SME was the feed moisture content. The SME decreased when the lower feed moisture was operated in the range of 12–15%. On the other hand, the SME decreased with increase in feed moisture for the moisture between 15 and 18% wet basis. From this study, extruding mushroom-rice snacks undergoing 13.5% of feed moisture, screw speed of 425 rpm and maximum barrel temperature at 130 °C could be considered as the optimum conditions that provided good physical properties of mushroom-rice snack, while consuming low total mechanical energy.

Acknowledgements This work was supported by Kasetsart University Research and Development Institute (KURDI). The authors are grateful to the Institute of Food Research and Product Development (IFRPD) for facilitating extrusion pilot plant, equipments and laboratory experiments.

References

Agathian G, Semwal AD, Sharma GK (2015) Optimization of barrel temperature and kidney bean flour percentage based on various physical properties of extruded snacks. J Food Sci Technol 52:4113–4123. https://doi.org/10.1007/s13197-014-1483-7

Akdogan H (1996) Pressure, torque, and energy responses of a twin screw extruder at high moisture contents. Food Res Int 29:423–429. https://doi.org/10.1016/s0963-9969(96)00036-1

Alam MS, Pathania S, Sharma A (2016) Optimization of the extrusion process for development of high fibre soybean-rice ready-to-eat snacks using carrot pomace and cauliflower trimmings. LWT Food Sci Technol 74:135–144. https://doi.org/10.1016/j.lwt.2016.07.031

Altan A, Maskan M (2012) Development of extruded foods by utilizing food industry by-products. In: Altan A, Maskan M (eds) Advances in food extrusion technology. CRC Press, Boca Raton

Awolu OO, Oluwaferanmi PM, Fafowora OI, Oseyemi GF (2015) Optimization of the extrusion process for the production of ready-to-eat snack from rice, cassava and Kersting's groundnut composite flours. LWT Food Sci Technol 64:18–24. https://doi.org/10.1016/j.lwt.2015.05.025

Bhattacharya M, Hanna MA (1987) Influence of process and product variables on extrusion energy and pressure requirements. J Food Eng 6:153–163. https://doi.org/10.1016/0260-8774(87)90037-9

Brennan MA, Derbyshire E, Tiwari BK, Brennan CS (2012) Enrichment of extruded snack products with coproducts from chestnut mushroom (*Agrocybe aegerita*) production: interactions between dietary fiber, physicochemical characteristics, and glycemic load. J Agric Food Chem 60:4396–4401. https://doi.org/10.1021/jf3008635

Camacho-Hernández IL, Zazueta-Morales JJ, Gallegos-Infante JA, Aguilar-Palazuelos E, Rocha-Guzmán NE, Navarro-Cortez RO, Jacobo-Valenzuela N, Gómez-Aldapa CA (2014) Effect of extrusion conditions on physicochemical characteristics and anthocyanin content of blue corn third-generation snacks. CYTA J Food 12(4):320–330

Chakraborty P, Banerjee S (2009) Optimization of extrusion process for production of expanded product from green gram and rice by response surface methodology. J Sci Ind Res (India) 68:140–148

Chang YK, Martinez-Bustos F, Park TS, Kokini JL (1999) The influence of specific mechanical energy on cornmeal viscosity measured by an on-line system during twin-screw extrusion. Braz J Chem Eng 16:285–295

Charunuch C, Limsangouan N, Prasert W, Wongkrajang K (2014) Optimization of extrusion conditions for ready-to-eat breakfast cereal enhanced with defatted rice bran. Int Food Res J 21:713–722

Chevanan N, Rosentrater KA, Muthukumarappan K (2008) Effect of DDGS, moisture content, and screw speed on physical properties of extrudates in single-screw extrusion. Cereal Chem 85:132–139. https://doi.org/10.1094/cchem-85-2-0132

Ding Q-B, Ainsworth P, Plunkett A, Tucker G, Marson H (2006) The effect of extrusion conditions on the functional and physical properties of wheat-based expanded snacks. J Food Eng 73:142–148. https://doi.org/10.1016/j.jfoodeng.2005.01.013

Feng Y, Lee Y (2014) Effect of specific mechanical energy on in vitro digestion and physical properties of extruded rice-based snacks. Food Nutr Sci 05:1818–1827. https://doi.org/10.4236/fns.2014.519196

Filli KB, Nkama I, Jideani VA, Ibok IU (2012) System parameters and product properties responses during extrusion of fura from millet-soybean mixtures. Niger Food J 30:82–100. https://doi.org/10.1016/s0189-7241(15)30017-5

Gat Y, Ananthanarayan L (2015) Effect of extrusion process parameters and pregelatinized rice flour on physicochemical properties of ready-to-eat expanded snacks. J Food Sci Technol 52:2634–2645. https://doi.org/10.1007/s13197-014-1378-7

Guerrero P, Beatty E, Kerry JP, de la Caba K (2012) Extrusion of soy protein with gelatin and sugars at low moisture content. J Food Eng 110:53–59. https://doi.org/10.1016/j.jfoodeng.2011.12.009

Gupta P, Premavalli KS (2012) Development of radish fibre based snack by response surface methodology (RSM). J Food Sci Technol 49:58–65. https://doi.org/10.1007/s13197-011-0261-z

Hood-Niefer SD, Tyler RT (2010) Effect of protein, moisture content and barrel temperature on the physicochemical characteristics of pea flour extrudates. Food Res Int 43:659–663. https://doi.org/10.1016/j.foodres.2009.09.033

Janes DA (1993) Methods for assessing raw materials and extrudates. Ingred Extra 12:9–34

Kaur A, Kaur S, Singh M, Singh N, Shevkani K, Singh B (2015) Effect of banana flour, screw speed and temperature on extrusion behaviour of corn extrudates. J Food Sci Technol 52:4276–4285. https://doi.org/10.1007/s13197-014-1524-2

Martínez-Soto G, Ocañña-Camacho R, Paredes-López O (2001) Effect of pretreatment and drying on the quality of oyster mushrooms (*Pleurotus ostreatus*). Dry Technol 19:661–672. https://doi.org/10.1081/drt-100103942

Min W, Yi L, Lijun W, Dong L, Zhihuai M (2015) Effects of extrusion parameters on physicochemical properties of flaxseed snack and process optimization. Int J Agric Biol Eng 8:121–131

Muthukumarappan K, Karunanithy C (2012) Extrusion process design. In: Rahman MS, Ahmed J (eds) Handbook of food process design. Wiley, New York

Omwamba M, Mahungu SM (2014) Development of a protein-rich ready-to-eat extruded snack from a composite blend of rice, sorghum and soybean flour. Food Nutr Sci 05:1309–1317. https://doi.org/10.4236/fns.2014.514142

Paula AM, Conti-Silva AC (2014) Texture profile and correlation between sensory and instrumental analyses on extruded snacks. J Food Eng 121:9–14. https://doi.org/10.1016/j.jfoodeng.2013.08.007

Piamvaree S, Jamjumroon S, Sasomsaup V, Inyod T, Sungkarn S (2011) Nutritive values of dried bhutan oyster mushroom (*Pleurotus eous*). Agric Sci J 42:9–12

Salgado N, Giraldo GI, Orrego CE (2017) Influence of the extrusion operating conditions on the antioxidant, hardness and color properties of extruded mango. LWT Food Sci Technol 86:209–218. https://doi.org/10.1016/j.lwt.2017.07.049

Seth D, Badwaik LS, Ganapathy V (2015) Effect of feed composition, moisture content and extrusion temperature on extrudate characteristics of yam-corn-rice based snack food. J Food Sci Technol 52:1830–1838. https://doi.org/10.1007/s13197-013-1181-x

Sharma C, Singh B, Hussain SZ, Sharma S (2017) Investigation of process and product parameters for physicochemical properties of rice and mung bean (*Vigna radiata*) flour based extruded snacks. J Food Sci Technol 54:1711–1720. https://doi.org/10.1007/s13197-017-2606-8

Singh SK, Muthukumarappan K (2016) Effect of feed moisture, extrusion temperature and screw speed on properties of soy white flakes based aquafeed: a response surface analysis. J Sci Food Agric 96:2220–2229. https://doi.org/10.1002/jsfa.7339

Stojceska V, Ainsworth P, Plunkett A, İbanoğlu Ş (2009) The effect of extrusion cooking using different water feed rates on the quality of ready-to-eat snacks made from food by-products. Food Chem 114:226–232. https://doi.org/10.1016/j.foodchem.2008.09.043

Thakur S, Singh N, Kaur A, Singh B (2017) Effect of extrusion on physicochemical properties, digestibility, and phenolic profiles of grit fractions obtained from dry milling of normal and waxy corn. J Food Sci 82(5):1101–1109

Tremaine AJ (2012) Twin-screw extrusion of commodity grade dairy ingredients to produce value-added products. University of Minnesota, Minneapolis