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ORIGINAL ARTICLE

Expansion and functional properties of extruded snacks enriched with nutrition sources from food processing by-products

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Abstract Rich sources of protein and dietary fiber from food processing by-products, defatted soybean meal, germinated brown rice meal, and mango peel fiber, were added to corn grit at 20 % (*w*/*w*) to produce fortified extruded snacks. Increase of total dietary fiber from 4.82 % (wb) to 5.92–17.80 % (wb) and protein from 5.03 % (wb) to 5.46–13.34 % were observed. The product indicated high expansion and good acceptance tested by sensory panels. There were 22.33–33.53 and 5.30–11.53 fold increase in the phenolics and antioxidant activity in the enriched snack products. The effects of feed moisture content, screw speed, and barrel temperature on expansion and nutritional properties of the extruded products were investigated by using response surface methodology. Regression equations describing the effect of each variable on the product responses were obtained. The snacks extruded with feed moisture 13–15 % (wb) and extrusion temperature at 160–180 °C indicated the products with high preference in terms of expansion ratio between insoluble dietary fiber and soluble dietary fiber balance. The results showed that the by-products could be successfully used for nutritional supplemented expanded snacks.

Keywords Extrusion cooking · Snack food · By-product · Dietary fiber · Phenolic compound

We developed corn-based extruded snacks with addition of food by-products.
The snacks developed indicated high nutrition and sensory acceptance.
The effects of extrusion variable on snack properties were studied.
Insoluble fiber converted to soluble fiber after extrusion cooking.
The enriched snacks showed good balance of insoluble and soluble dietary fiber.

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Introduction

Extruded snacks were among the most commercially successful extruded foods. Extrusion cooking is the process extensively used for the production of snacks which are mainly produced from cereal flour or starches. Extruded snacks are normally high in calories and fat with low content of protein, fiber, and perceived as unhealthy food to many consumers. Thailand is one of the world leaders for food product export. Consequently, a large quantity of by-products from food processing plants such as fruit and vegetables, rice, fat and oil is available. These by-products cause a major disposal problem for the industry. However, they still contain a lot of nutrients and can be promising sources for food supplementation (Larrea et al. 2005; Wandee et al. 2014). Several attempts to improve the nutritional profile of extruded starch by using food by-products have been reported (Onwulata et al. 2001; Stojceska et al. 2008).

Defatted soybean meal from soybean oil processing contains more than 40 % of protein. Soy protein is highly nutritious, inexpensive and widely used in many food products such as meat, dairy, cereal product, snack food and rice pasta (Sereewat et al. 2015). Germinated brown rice contains many nutritional components such as dietary fiber, mineral, essential amino acid and γ-aminobutyric acid (GABA). The inhibitory neurotransmitter, GABA, accumulated in rice germ during soaking can prevent hypertension and Alzheimer's disease. Ajila et al. (2008) reported that mango peel was a good source of bioactive compounds such as polyphenol, carotenoids and dietary fiber (DF) and they were added in pasta to increase the nutraceutical properties of the product (Ajila et al. 2008). Recently, we have reported the potential of selected tropical fruit peels as dietary fiber in functional foods (Wanlapa et al. 2015). Kaeo mango peel DF exhibited noticeable properties, as revealed by the high total dietary fiber (TDF), high soluble dietary fiber (SDF), well-balanced DF fraction, low fat, protein and ash content, high total polyphenol and flavonoid contents, high antioxidant capacity, and moderate ability to hold water and oil. In addition, the phenolic compound in the mango peel is noticeably higher than the amount found in the red grape seed, 14.3–22.28 mg GAE/100 g, (Wanlapa et al. 2015; Negro et al. 2003). It was also found that mango is one of the seven fruits which indicated the largest volume of peel in Thai fruit processing plants.

Dietary fiber and phenolic compounds are gaining increased attention because these phytochemicals indicate health promoting benefit as antioxidant, anticarcinogenic, and antimutagenic properties (Block and Langseth 1994). Dietary fiber can be classified into insoluble and soluble fiber fractions, based on its water solubility properties (Tungland and Meyer 2002). Insoluble fibers are composed of cellulose, hemicellulose and lignin, which stimulate an increase in fecal bulk, reduced transit time of fecal through the large intestine (Rodŕiquez et al. 2006). The soluble fibers include pectins, β-glucans and galactomannan gums, can help to lower blood cholesterol and regulate blood glucose levels. Consumption of either soluble fiber or vegetable protein could decrease serum cholesterol (Jenkins et al. 1999).

Extrusion cooking may change dietary fiber, protein and amino acid profile, vitamins, and other nutrient in both positive and negative effect on the food (Singh et al. 2007). Functional quality has been improved with moderate conditions (short duration, high moisture, low temperature), whereas a negative effect occurs at a high temperature (at least 200 °C), low moisture (less than 15 %), or improper components in the mix (Singh et al. 2007). The change of insoluble dietary fiber to soluble fiber after the extrusion of orange pulps was reported (Larrea et al. 2005) as well as the increase of total phenolic compounds and total antioxidant capacity of the extrudate with cauliflower by-product (Stojceska et al. 2008). The addition of high-fiber, high protein alternate ingredients to starch significantly affect the texture, expansion and overall acceptability of the extruded snack (Veronica et al. 2006).

Mixing different ingredients to make a puffed snack product using the extrusion is difficult (Lobato et al. 2011). Consequently, the potential to use three main food processing by-products, defatted soybean meal, germinated brown rice meal and mango peel fiber as sources of protein, dietary fiber and antioxidant in corn-based snack food was investigated in this study. The effects of the extrusion variables including feed moisture content, screw speed and temperature of the extruder on expansion and functional properties of the extruded snacks were investigated by using response surface methodology.

Materials and methods

Materials and sample preparation

Defatted soybean meal (DSM) and germinated brown rice meal (GBM) were kindly obtained from Thai Vegetable Oil, Public Co., Ltd. and Ampol Food Processing Co., Ltd., respectively. Mango peel fiber (MPF) prepared from Kaeo mango peel was obtained from Samroiyod Co., Ltd. All samples were dried and milled using a 0.5 mm mesh screen, packed and sealed in polyethylene bags until they were used. Official methods (AOAC 2000) were used to analyze moisture, protein, fat and ash content of raw materials and the extruded snacks.

Effect of by-product addition and determination of snack formulation

The control formulation was composed of corn grit 83.5 %, wheat flour 8 %, rice flour 8 % and margarine 0.5 % (all in % wet weight basis, wb). A mixture design was chosen to create 13 formulations to extrude the snack with DSM, GBM and MPF substitution at 0–20 % (expressed as mixture ratio, x, 0–1.0) of corn grit. The moisture of blended samples were conditioned to 14 % (wb) before the extrusion. The laboratory single-screw extruder (Brabender 19/20, DGE 330, PL 2200, Germany) with barrel bore (D), 19.1 mm, barrel length (L) and a screw of 4:1 compression ratio was used to produce the snack food product. The barrel consists of three independent temperature zones, zone 1 (entering zone), zone 2 (kneading zone) and at the barrel end, indicated as zone 3. The exit diameter of the circular die was 3 mm.

The extrusion was carried out with following conditions; 180 rpm of screw speed and barrel temperature zone 1:2:3 as 120:170:180 °C respectively while feeder screw speed was set at 30 rpm throughout the experiments. The extrudates were dried in a hot air oven at 60 °C (Memmert, Germany) until their moisture was reduced to about 2–3 % (wb). Dried samples were stored in polyethylene bags at room temperature and used for further analysis.

The products were served to the panelists with 8–10 pieces on a plate. Nine point hedonic scales were adopted and the categories were rated from 1 (extremely dislike) to 9 (extremely like) in order to evaluate the preference of the products. The attributes examined were color, flavor, texture, after taste and overall acceptance. The test panel consisted of 30 untrained panelists who were students [female and male (7:3), 20–23 years old] from the Department of Agro-Industrial, Food and Environmental Technology, Faculty of Applied Science, KMUTNB. Finally, formulation 9 which consisted of corn grit 63.5 %, wheat flour 8 %, rice flour 8 %, margarine 0.5 %, MPF 8.6 %, GBM 7.4 %, and DSM 4 % at moisture content 14 % (wb), was selected to study the effects of process parameters on physical and nutritional properties of the extruded snacks.

The product properties in terms of ER and TDF content were analyzed using SPSS 11.5 program (SPSS Inc., Chicago, Ilinois, US) and the differences between each formulation and the sensory data were determined by Duncan's multiple range test (Duncan 1955).

Experimental design

The effects of three independent extrusion parameters (variables), feed moisture content (X_1), screw speed (X_2) and barrel temperature of zone 3 (X_3) on physical and nutritional properties of the products were studied by using the central composite design. All variables were controlled at five different levels with $\alpha = 1.68$ according to the theory and rules of Box and Wilson (1951). Totally 17 runs using the composition of formulation 9 and a control in run no 18 (no addition of by-product) were carried out. The barrel temperature of zone 1 and 2 was controlled at 120 and 170 °C while feeder screw speed was set at 30 rpm throughout the experiments. Dependent variables, as product responses, were ER, bulk density (BD), hardness, and functional properties such as insoluble dietary fiber (IDF), SDF, TDF, total phenolic compound (TPC), and free radical antioxidant capacity (IC_{50}). All experiments were done with two replications.

Response surface methodology was applied for experimental data using a commercial statistical package, Design Expert (version 8.0) for the generation of response surface plot and statistical analysis of the experimental data. The second-order polynomial model was selected to predict the optimal point of the responses, and expressed as following.

$$y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{11} X_1^2 + \beta_{22} X_2^2 + \beta_{33} X_3^2 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 \quad (1)$$

where y represented the response variable, β_0 was the intercept while β_1, β_2 and β_3 were linear terms with β_{12}, β_{13} and β_{23} as interaction terms and β_{11}, β_{22} and β_{33} as quadratic terms. X_1, X_2 and X_3 were independent variables, coded for moisture content, screw speed and barrel temperature, respectively.

A superimposed contours at 180 rpm of screw speed was performed to find the optimum extrusion condition with each responses set as proposed optimum values, ER at 3, BD at 0.115 g/cm^3, hardness at 340 N, SDF at 3.5 % (wb), IDF/SDF at 2, TPC at 10 mg GAE/g sample and IC_{50} at 5 mg sample, sensory score for texture and overall acceptance at 6 (from 9 scale). Model validation aspect was carried out with feed moisture content of 13 % (wb), screw speed 180 rpm, barrel temp 160 °C. Predicted and observed values of the response variables were compared and analyzed statistically.

Determination of product properties

Expansion ratio (ER) and bulk density (BD)

Twenty pieces of the extrudates were randomly selected and the expansion ratio as well as bulk density of the extrudate were determined following the method of Alarez-Martinez et al. (1988).

Texture measurement

The hardness of the extrudate was measured by using a texture analyzer TA-XT2 (Stable Micro System Co., Ltd., UK) equipped with a 5 kg load cell and a 5-blade Kramer shear cell following Lobato et al. (2011) with slight modification. Hardness in N was determined by measuring the maximum force required to break the extruded samples. The test speed was 1 mm/s with 50 % strain. The samples were cut by hand and approximately 60 pieces were put horizontally in multiple layers in the cell to fill up to a standard height of 2 cm. Ten replications were conducted for samples from each treatment.

Dietary fiber

TDF, SDF and IDF of the raw materials and extrudates were determined using enzymatic and gravimetric methods following AOAC (2000) and Prosky et al. (1988) with Megazyme analysis kit. The samples were hydrolyzed with heat stable α-amylase, protease and amyloglucosidase to remove protein and starch in the sample. Ethanol (95 %) was added to precipitate the soluble dietary fiber. SDF was calculated from TDF-IDF. All analyses were carried out in triplicate and expressed as the mean value.

TPC and IC_{50}

TPC was determined using Folin-Ciocalteau method (Singleton et al. 1999) with slight modification. The concentration of total phenolic content in the sample was expressed as mg of gallic acid equivalents (GAE) per 1 g of sample. The antioxidant activity in the methanol extract of the samples was determined by free radical scavenging activity by using 2, 2-

diphenyl-1-picrylhydrazyl (DPPH) following the method of Brand-Williams et al. (1995). The percentage of free radical scavenging activity was plotted against the amount of sample and half-inhibition concentration (IC_{50}) was calculated.

Result and discussion

Chemical composition of raw materials

Chemical compositions of the by-products were exhibited in Table 1. The protein contents of DSM and GBM were 45.12 and 44.36 % (wb) while TDF of both by-products were 16.29 and 5.41 % (wb), respectively. Comparatively, MPF has low protein content (5.68 %, wb) but indicated highest TDF content (64.64 %, wb), phenolic content (84.55 mg GAE/g sample) and strong free radical scarvenging activity, IC_{50}, at 0.05 mg. The SDF content in mango peel was 27.72 % (wb).

Effect of by-product addition and determination of snack formulation

Table 2 summarizes the impact of adding DSM, GBM, and MPF on ER and TDF of corn based extrudates obtained from 13 formulations. As expected, the substitution of corn grit with all by-products resulted to snack with lower expansion (2.19–3.14) compared to ER of the control (4.09). The product substituted with DSM and GBM at 20 % (formulation 10 and 11) exhibited significant decrease in expansion ratio (2.58 and 2.19). The use of DSM and GBM which composed of high protein (45.12 and 44.36 %, wb) with moderate and low TDF (16.29 and 5.41 %, wb) significantly decreased the snack expansion than the corn substitution by MPF which composed of high SDF at 27.72 % (wb) and low protein content (5.68 %, wb). Soluble dietary fiber usually indicates higher expansion volumes and affect less the bulk density of extruded products than insoluble dietary fiber such as cereal bran fiber (Blake 2006). The texture of the extruded snacks is greatly influenced by the extrudate composition. Increasing protein content results in a less expanded, higher bulk density and more compacted extrudate texture. The air bubbles were smaller with less porous structure. In general the addition of the by-products which had high protein and dietary fiber to an extruded product resulted in increased product density and hardness. Increasing amount of by-product diluted the concentration of starch in the blend and the interaction between these components and the starch resulted to less expanded products. The addition of protein to extrudate reduced the ER of products by reducing the extensibility of the starch polymer during its expansion at the die exit (Camire and King 1991). The fiber can also rupture cell wall and inhibit air bubbles from expanding to their maximum capacity. Similar results were reported for corn based snack with common bean flour (Anton et al. 2009) and the co-extrusion of corn meal with increased corn bran content (Mendoça et al. 2000).

Table 1 Chemical composition of defatted soybean meal, germinated brown rice meal and mango peel fiber

Component (%wb)	DSM	GBM	MPF
Moisture	3.71 ± 0.03	8.53 ± 0.09	8.27 ± 0.05
Protein	45.12 ± 0.09	44.36 ± 0.12	5.68 ± 0.08
Fat	1.27 ± 0.08	4.28 ± 0.07	3.38 ± 0.06
Ash	5.95 ± 0.03	1.88 ± 0.01	2.86 ± 0.04
Total dietary fiber	16.29 ± 0.16	5.41 ± 0.22	64.64 ± 0.18
Soluble dietary fiber	4.83 ± 0.20	2.56 ± 0.34	27.72 ± 0.13
Insoluble dietary fiber	11.46 ± 0.18	2.85 ± 0.23	36.92 ± 0.27
Total phenolics (mg GAE/g sample)	4.10 ± 0.05	0.60 ± 0.04	84.55 ± 0.05
Free radical scarvenging activity, IC_{50} (mg sample)	64.94 ± 0.11	48.44 ± 0.09	0.05 ± 0.07

Total dietary fiber in the snack was significantly increased from 4.82 % (wb) to 5.92–17.80 % (wb), or 1.22–3.69 folds, which was higher than 10 % Thai RDI in the formulations with MPF substitution. Protein content in the extrudates can be increased from 5.03 % (wb) in the control upto 5.46–13.34 % or 1.08–2.65 folds or more than 10 % Thai RDI in many formulations. Attempts have been made to add nutrients such as protein and fiber to the snack products in many studies (Veronica et al. 2006; Stojceska et al. 2008; Anton et al. 2009). The addition of whey protein at 25 wt% to corn, rice and potato flour to produce snack resulted to the increase of fiber and protein content (Onwulata et al. 2001). There are many reports suggested that as high-fiber, high protein materials are added to starch-based extruded snack, density and hardness are expected to increase (Onwulata et al. 2001; Veronica et al. 2006). Cereal fibers was added to extruded products to a maximum limit of 10–30 % fiber substitution for flour due to the increase in product hardness and decrease in consumer acceptance (Hsieh et al. 1989). In our study, the substitution of by-products was limited to 20 % of the corn grit.

The regression equations for ER and TDF at any mixture ratio of DSM (x_1), GBM (x_2), and MPF (x_3) in the blend were:

$$\mathrm{ER} = 2.844x_1 + 2.835x_2 + 3.140x_3 \quad R^2 = 0.974 \tag{2}$$

$$\mathrm{TDF} = 7.089x_1 + 4.916x_2 + 16.790x_3 \quad R^2 = 0.986 \tag{3}$$

From the Thai food regulation, the snack contains total dietary fiber 20 % and up of Thai RDI (Thai recommended daily intake, RDI) can be claimed as “high” or “rich in dietary fiber” while “good source, contains, provides dietary fiber” shall be claimed for product with 10 to 19 % of Thai RDI. Consequently, the extrudates from formulation 3, 4, 5, 6 and 9 which exhibited ER higher than 3.0 (as generally accepted for expanded snack food) and TDF of 10 % up were chosen for

Table 2 Expansion ratio and total dietary content of snacks prepared from 13 formulation contained by-products at different mixture ratio

Formulation	By-product mixture ratio			ER	TDF (% wb)	Thai RDI (%)	Protein
	DSM	GBM	MPF				(% wb)
1	0.50	0.25	0.25	2.82 ± 0.28[c]	9.93 ± 0.04[d]	11.9	11.35
2	0.25	0.50	0.25	2.84 ± 0.20[c]	9.39 ± 0.07[d]	11.3	11.32
3	0.50	0	0.50	3.13 ± 0.15[f]	12.92 ± 0.06[f]	15.5	9.40
4	0	0.50	0.50	3.14 ± 0.14[f]	11.83 ± 0.03[e]	14.2	9.35
5	0.25	0.25	0.50	3.01 ± 0.08[e]	12.47 ± 0.10[f]	14.8	9.37
6	0.25	0	0.75	3.04 ± 0.14[e]	15.31 ± 0.05[h]	18.4	7.43
7	0	0.25	0.75	2.93 ± 0.18[d]	14.88 ± 0.12[g]	17.7	7.40
8	0.37	0.20	0.43	2.93 ± 0.20[d]	11.85 ± 0.03[e]	14.1	9.93
9	0.20	0.37	0.43	3.06 ± 0.16[f]	11.41 ± 0.08[e]	13.7	9.91
10	1.0	0	0	2.58 ± 0.38[b]	8.06 ± 0.05[c]	9.7	13.34
11	0	1.0	0	2.19 ± 0.18[a]	5.92 ± 0.02[b]	7.1	13.24
12	0	0	1.0	2.85 ± 0.23[c]	17.80 ± 0.09[i]	21.3	5.46
13 (Control)	0	0	0	4.09 ± 0.16[g]	4.82 ± 0.08 [a]	5.8	5.03

Values with the same letter in the same column are not significantly different at $p \leq 0.05$ level

sensory evaluation. Sensory attributes for flavor, after taste, and overall acceptability of the products from these five formulations were not significantly different ($p \geq 0.05$) as shown in Table 3. However, the extrudate from formulation 9 which contained MPF at 8.6 % obtained higher sensory score for in the color attribute compared to the other samples. Similar result was reported by Ajila et al. (2008) that the color of biscuits supplemented with mango peel fiber more than 10 % was relatively dark and less acceptable by sensory evaluation.

As a result, the product from formulation 9 which exhibited ER at 3.06 and TDF content about 11.41 %, (calculated as 13.7 % Thai RDI) and protein content of 9.91 % (wb) was selected for further study.

Effect of extrusion process on expansion and functional properties

Expansion ratio, bulk density, and hardness

The extruded snack had cylindrical shape with porous structure. Expansion ratio of the extrudates varied between 2.14 and 3.18 compared to 4.09 of the extrudate from the control without by-product addition (Table 4). Cross section of selected corn-based snacks extruded with different feed moisture content, screw speed and barrel temperature were pictured in Fig. 1. Feed moisture content and barrel temperature were found to have the most significant effect on extrudate expansion, bulk density and hardness. Gelatinization, molecular degradation and/or reassociation during extrusion influence the final textural and functional properties of the product. The maximum ER (3.18) was observed to be at feed moisture content 13 % (wb), 180 rpm screw speed and 160 °C and the minimum ER (2.14) was observed to be at feed moisture content 17 % (wb), 180 rpm screw speed and 200 °C. The product with ER 3.18 of run-3 indicated higher TPC and free radical antioxidant capacity and also crispier than the product with ER 2.14 of run-8.

As shown in Fig. 2 (a-b), when the screw speed was fixed at 180 rpm, the ER increased with increasing feed moisture content from 11.64 to 15 % (wb) and

Table 3 Mean scores for sensory properties of snacks prepared from 5 formulations

Formulation	Color	Flavor [ns]	Texture	After Taste [ns]	Overall Acceptance [ns]
3	4.97 ± 1.35[a]	6.03 ± 1.16	5.43 ± 1.60[a]	5.33 ± 1.67	5.43 ± 1.36
4	5.79 ± 1.30[bc]	5.60 ± 1.35	6.06 ± 1.60[ab]	5.30 ± 1.56	5.93 ± 1.48
5	5.65 ± 1.50[abc]	5.60 ± 1.25	5.72 ± 1.57[ab]	5.57 ± 1.48	6.03 ± 1.56
6	5.28 ± 1.05[ab]	5.33 ± 1.18	5.67 ± 1.40[ab]	5.33 ± 1.42	5.57 ± 1.19
9	6.32 ± 1.05[c]	5.40 ± 1.35	6.42 ± 1.26[b]	5.43 ± 1.68	6.13 ± 1.38

Value with the same letter in the same column are not significantly different at $p \leq 0.05$. ns: not significantly different ($p > 0.05$)

Table 4 Physical and nutritional characteristics of finished products obtained from 18 extrusion runs

Run	Feed MC (% wb)	Screw speed (rpm)	Barrel temp (°C)	ER	BD (g/cm^3)	Hardness (N)	IDF (% wb)	SDF (% wb)	IDF/SDF	TDF (% wb)	TPC (mg GAE/g sample)	IC_{50} (mg sample)
1	13	140	160	3.07	0.115	317	6.28	3.43	1.83	9.71	7.72	4.05
2	13	140	200	3.02	0.116	328	5.82	3.10	1.88	8.92	6.70	5.92
3	13	180	160	3.18	0.108	297	5.64	3.55	1.59	9.19	9.29	3.71
4	13	180	200	2.90	0.114	336	4.52	4.32	1.05	8.84	8.78	3.17
5	17	140	160	2.69	0.147	336	6.20	3.84	1.61	10.04	8.68	4.48
6	17	140	200	2.46	0.128	345	6.70	2.50	2.68	9.20	8.17	4.60
7	17	180	160	2.54	0.137	343	6.39	2.69	2.38	9.08	7.53	5.69
8	17	180	200	2.14	0.156	353	5.94	3.81	1.56	9.75	7.51	5.76
9	17	160	180	2.62	0.135	341	6.29	3.57	1.76	9.86	7.89	4.48
10	11.64	160	180	2.64	0.136	340	5.17	3.75	1.38	8.92	8.28	3.95
11	18.36	126	180	2.29	0.151	342	5.66	3.98	1.42	9.64	7.28	4.68
12	15	194	180	2.93	0.124	300	4.79	4.13	1.16	8.92	7.24	4.11
13	15	160	146	2.82	0.125	335	5.01	4.05	1.24	9.06	10.06	3.61
14	15	160	214	2.72	0.130	326	4.27	4.46	0.96	8.73	6.85	6.89
15	15	160	180	3.11	0.112	307	5.10	4.29	1.19	9.39	7.55	6.26
16	15	160	180	3.08	0.111	305	4.81	4.44	1.08	9.25	7.52	6.31
17	15	160	180	3.10	0.109	310	5.06	4.36	1.16	9.42	7.41	6.12
18 (Control)*	14	180	180	4.09	0.084	273	3.68	1.12	3.29	4.82	0.30	36.56
Nonextruded sample (with by-product) (calculated at 2 % wb moisture content)							11.57	2.26	5.12	13.84	15.88	0.94

Run 1–17: Use the same formulation of the raw material blend as described in materials and methods

Control: the formulation without by-product addition

decreased beyond that. Increasing in expansion at lower moisture content in feed was probably resulted from high viscosity caused by the low moisture level which related directly to shear stress of the plasticized mass and the increased degree of gelatinization (van Langerich 1990). Increasing the moisture content during extrusion may reduce the elasticity of the dough through plasticization of the melt and therefore reduced gelatinization, decreased expansion and increased the density (Thymi et al. 2005).

Expansion ratio also increased with the increase of barrel temperature in the range of 146–180 °C and decreased beyond that. This may be because higher barrel temperature could increase the degree of gelatinization and also the extent of superheated steam that causes the snack to expand more. Temperature determines the vapor pressure of the moisture and thus degree of puffing. Higher temperature lowered the viscosity of the dough mass in the extruder and hence resulted in higher linear velocity at the die (Hsieh et al. 1989). On the other hand, the decreased ER beyond the critical temperature, which depends on the type of starch and moisture content, could be resulted from the increase of dextrinization, excessive softening and potential structural degradation of the starch melt which could not withstand the high vapour pressure and collapsed (Mendoça et al. 2000).

Similar models for the effects of barrel temperature and feed moisture content on ER were observed at all screw speeds examined. This result is in line with those for density and hardness of the extrudates. The increase of expansion resulted in a product with lower density that was crispier. Regression analysis for ER, BD and hardness at any feed moisture content (X_1), screw speed (X_2), barrel temperature (X_3) were shown in Eqs. (4)-(6). The coefficient of determinations of regression equations (R^2) for these process variables and product properties ranged 0.784–0.956. These models are important in order to choose the condition that yields the required properties of the products.

$$ER = -26.54 + 2.38X_1 + 0.028X_2 + 0.12X_3 - 0.069X_1^2 - 0.002X_1X_2 - 0.001X_1X_3 \quad R^2 = 0.956 \tag{4}$$

$$BD = -1.12 + 0.09X_1 + 0.006X_3 - 0.002X_1^2 + 2.78X10^{-6}X_2^2 \tag{5}$$

$$Hardness = 895.98 - 85.18X_1 + 3.64X_2 - 3.084X_3 + 3.73X_1^2 - 0.015X_2^2 + 0.016X_3^2 + 0.063X_1X_2 - 0.17X_1X_3 + 0.001X_2X_3 \quad R^2 = 0.784 \tag{6}$$

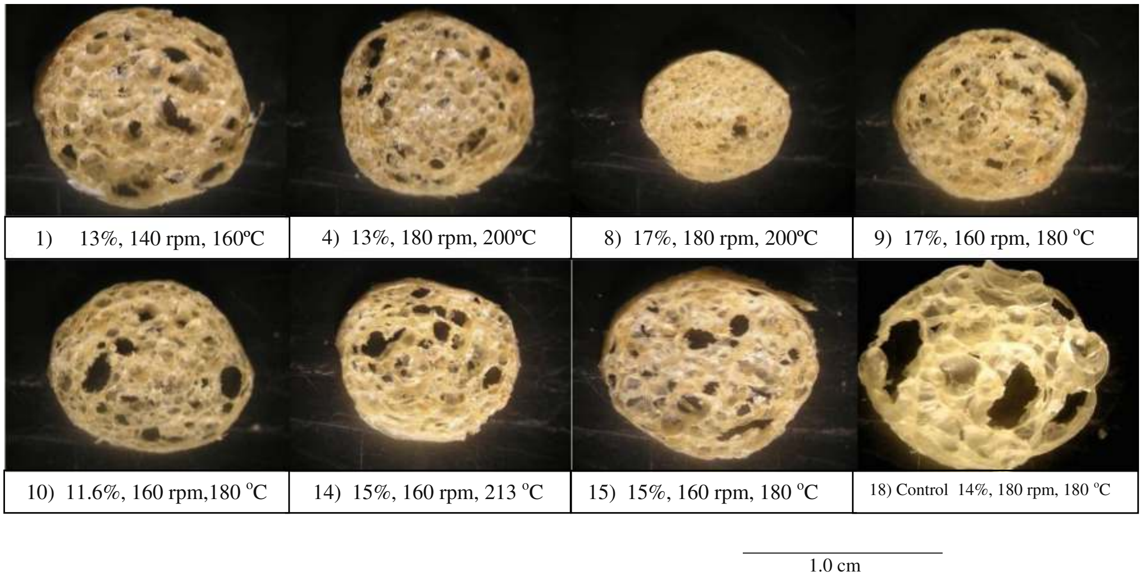

Fig. 1 Cross section of the corn-based snack extruded with different % feed moisture content, screw speed and barrel temperature

Effect of extrusion process on functional properties of the snack

Total, insoluble, and soluble dietary fiber

There is a significant decrease in IDF (4.27–6.70 % wb) and increase of SDF (3.10–4.46) in extruded snacks compared to nonextruded sample (IDF 11.57 % wb, SDF 2.26 % wb). The ratio of SDF/IDF, which is nutritionally significant, decreased from 5.12 in the nonextruded sample to 0.96–2.68 after the extrusion processing. Converting insoluble dietary fiber into soluble fiber by extrusion cooking can significantly improve their nutritional properties and thus increase its application potential in human nutrition. The well-balanced values between ISF and DSF according to the recommendation of Spiller (1986) were 1.0–2.3 in order to obtain the physiological effect associated with both soluble and insoluble fractions.

At the same screw speed, in general, the decrease of IDF was observed when the barrel temperature and moisture content were increased. When the moisture content was fixed at 15 % (wb), the lowest value of IDF was obtained at high temperature with screw speed 160 rpm (Fig. 3a). The effect was reverse for SDF as shown in Fig. 3b. Similar trends were observed with moisture content at 15 and 17 % (wb).

Similar results were obtained from the extrusion of orange pulps to modify the properties of the fiber components (Larrea et al. 2005) and the use of extrusion to solubilize pectic substances from sugar-beet pulp by-products (Ralet et al. 1991). The authors (Larrea et al. 2005) reported that total dietary fiber content in orange pulps decreased with higher barrel temperatures and lower moisture contents with the screw speed fixed at 160 rpm.

It can be seen from Tables 4 and 5 that TDF of the extruded snack were decreased after the extrusion.

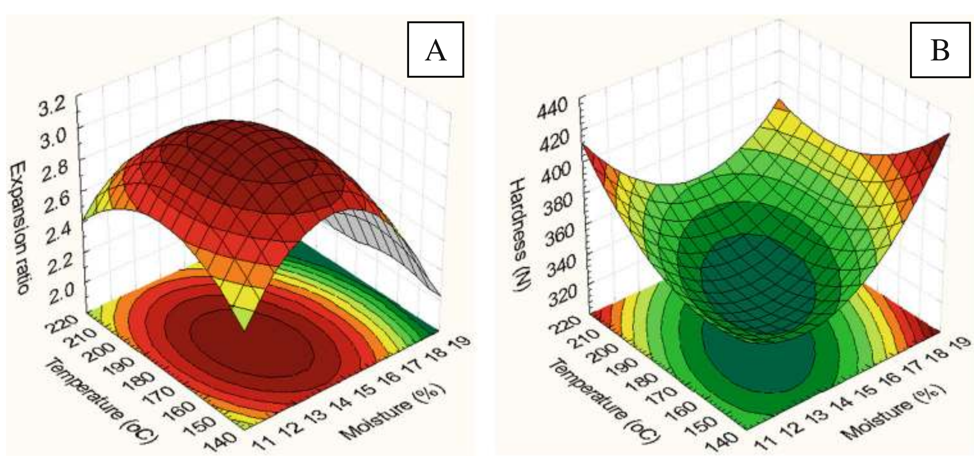

Fig. 2 RSM on the effects of barrel temperature and % feed moisture content on expansion ratio (**a**) and hardness (**b**) of the extruded snacks (screw speed 180 rpm)

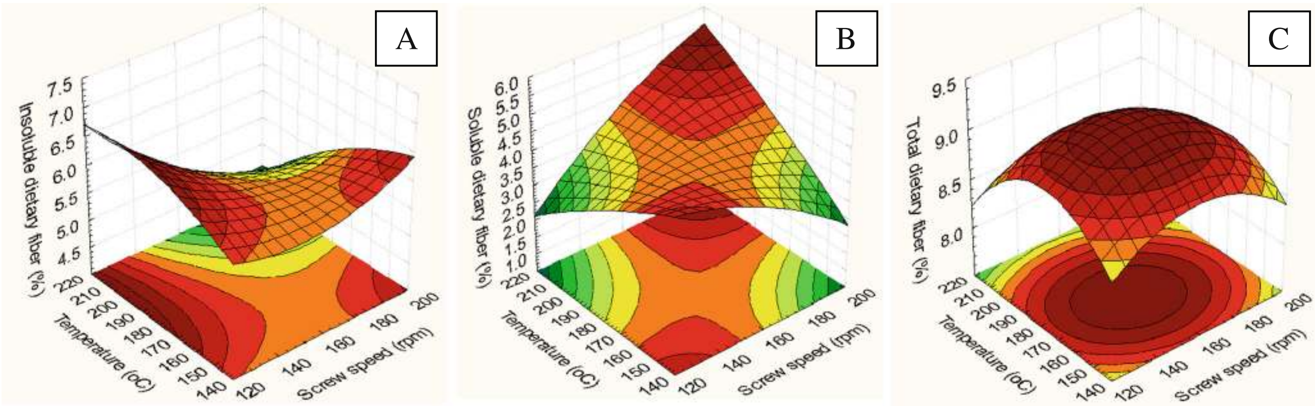

Fig. 3 RSM on the effects of barrel temperature and screw speed on insoluble dietary fiber (**a**), soluble dietary fiber (**b**), and total dietary fiber (**c**) of the extruded snacks (% feed moisture content at 13 %)

During extrusion cooking, glycosidic linkages in the TDF polysaccharides may be broken causing solubilisation of IDF into SDF which might be degraded due to heat and moisture leading to the decrease in the fiber content (Larrea et al. 2005; Stojceska et al. 2008). If small molecular mass fragments were formed, there might be a falsely low value in TDF content as discussed by Nyman (1995).

The RSM plot in Fig. 3C shows the increase of TDF in the extrudate follows the increase of barrel temperature and screw speed from 140 °C to about 180 °C and 120 rpm to about 180 rpm, respectively, and decreases beyond that. Regression equations for TDF at any feed moisture content (X_1), screw speed (X_2), barrel temperature (X_3) were exhibited in equation (7) but those equations for IDF and SDF indicated low R^2 at only 0.674 and 0.668 (equations not shown).

$$\begin{aligned} TDF &= 25.88 - 0.90X_1 - 0.097X_2 - 0.017X_3 + 0.007{X_1}^2 \\ &\quad + 0.002X_1X_2 + 0.003\,X_1X_3 + 0.001X_2X_3 \\ R^2 &= 0.854 \end{aligned} \tag{7}$$

Table 5 Predicted and observed values for the response variables

Response variable	Predicted value	Observed value
ER ^{ns*}	3.07	3.18 ± 0.11
BD (g/cm^3) ^{ns*}	0.11	0.11 ± 0.01
Hardness (N) ^{ns*}	305	297 ± 11.51
TDF (% wb) ^{ns*}	9.12	9.19 ± 0.14
TPC (mg GAE/g sample) ^{ns*}	9.36	9.29 ± 0.07
IDF (% wb) ^{ns**}	5.98	5.64 ± 0.13
SDF (% wb) ^{ns**}	3.40	3.55 ± 0.06
IDF/SDF ^{ns**}	1.76	1.59 ± 0.01
IC_{50} (mg sample) ^{ns**}	3.26	3.71 ± 0.02

ns* : Not significant for t-test at $p < 0.05$

ns** :Not significant for t-test at $p < 0.1$

Total phenolic compound and free radical antioxidant capacity

The TPC and IC_{50} in the control and enriched snacks showed that incorporation of by-products increased the content of phenolics in the snacks from 0.3 to 6.7–10.06 mg GAE/g snack and IC_{50} was reduced from 36.56 to 3.17–6.89 mg snack depended on extrusion conditions (Table 4). There were 22.33–33.53 and 5.30–11.53 fold increase in the phenolics and antioxidant activity in the snack product enriched with the by-products, especially MPF. However, there were losses in the phenolic compound and antioxidant capacity during processing, around 36.64–56.86 % and 3.37–7.32 folds, respectively. Extrusion at high temperature tended to decrease TPC and increase IC_{50} of the extrudate as exhibited in Fig. 4a and b. Many phenolic compounds are easily hydrolyzed and oxidized. Using high temperature increases the chance of oxidation of phenolics which decrease the yield of TPC, thus reducing the antioxidant capacity (Jackman et al. 1987). To tackle this problem is to select the optimum condition for the extrusion. The extrusion conditions especially the barrel temperature should not be too high and must be able to give crispy product. A superimposed contours at 180 rpm of screw speed to find the optimum extrusion condition was performed as shown in Fig. 5.

Our results were in accordance with previous reports on polyphenols and antioxidant activities of raw, extruded common beans and snack fortified with common bean (Anton et al. 2009). Ajila et al. (2008) reported some loss of phenolics in the enriched biscuits with MPF during processing while roasting or extrusion of buckwheat flour did not change the phenolic content (Sensoy et al. 2006). Additionally, it is reported that extrusion may have also activated the polymerization of phenolic acids and tannin (Stojceska et al. 2008) resulted to better extractability of such compounds and

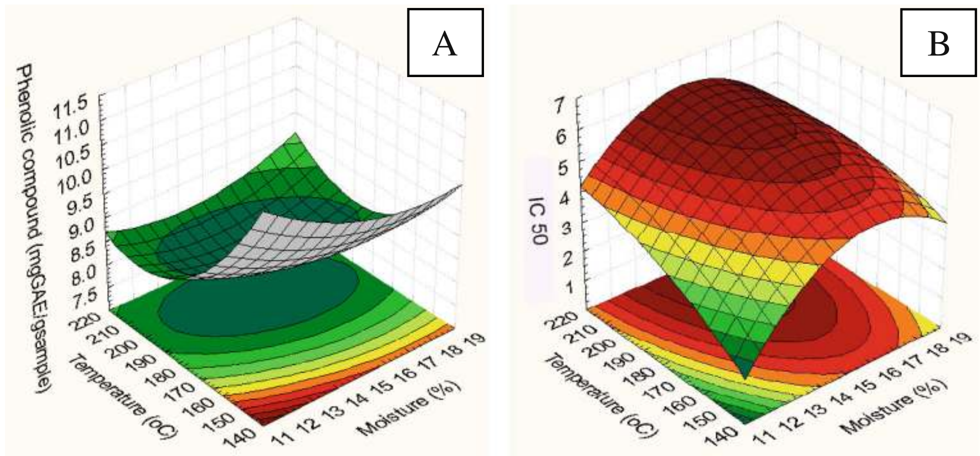

Fig. 4 RSM on the effects of barrel temperature and % moisture content on phenolic compound (**a**) and IC_{50} (**b**) of the extruded snacks (screw speed 160 rpm)

their related antioxidant activities. Regression analysis for TPC and three extrusion parameters is expressed in following equation.

$$TPC = 14.33 + 0.205X_1 + 0.42X_2 - 0.44X_3 + 0.039X_1^2 - 0.001X_2^2 + 0.001X_3^2 - 0.012X_1 + 0.003X_1X_3$$
$$R^2 = 0.772 \quad (8)$$

Applying the optimization technique and aiming at obtaining ER higher than 3.00 led to optimal process conditions of 13–15 % (wb) MC and extrusion temperature at 160–180 °C (run 1, 2, 3, 15, 16, and 17). The products obtained from these extrusion conditions showed well balance of IDF:SDF ratio where the extrudate from run 3 (13 % MC, 180 rpm and 160 °C) exhibited maximum ER (3.18), TPC (9.29 mg GAE/g sample) and high antioxidant activity as low IC_{50} of 3.71 mg sample. Comparison of predicted and observed values of the response variables by model validation showed that the model could be used to predict ER, BD, hardness, TDF, and TPC ($p > 0.05$), IDF, SDF, IDF/SDF, and also IC_{50} ($p > 0.1$).

Conclusion

This work demonstrated the substitution of corn grit at 20 % (*w/w*) with nutrition rich by-products, defatted soybean meal, germinated brown rice meal, and mango peel fiber, into ready to eat snacks with higher protein content (upto 2.65 folds), dietary fiber (more than 3 folds), total phenolic compound (22.33–33.53 folds), and antioxidant activity (5.30–11.53 folds). Increasing the protein and fiber content in the product resuted in decreased expansion ratio but the snack products

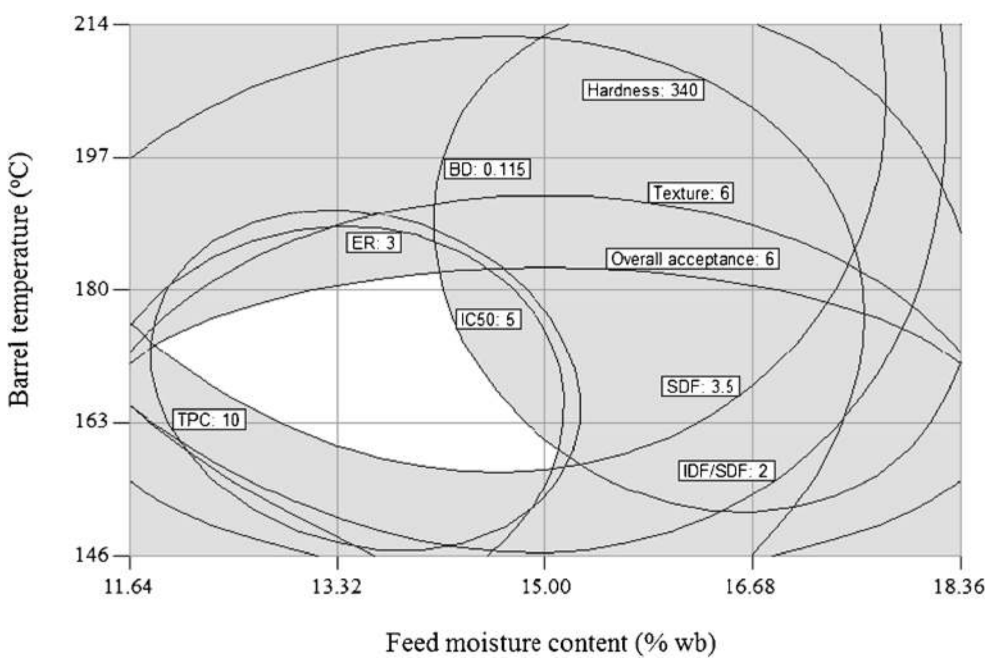

Fig. 5 Superimposed contours at 180 rpm of screw speed to find the optimum extrusion condition (indicated in the white area)

still obtained good sensory characteristics. Extrusion cooking resulted in the conversion of insoluble to soluble fiber and well balance of both types of the fiber. Extrusion also decreased total phenolic compound and antioxidant capacity. The product extrudated from the blend with 13 % (wb) MC at 180 rpm and 160 °C showed high ER, TPC and antioxidant capacity. It appears that the snack fortified with three by-products indicated a strong potential to be a healthier option than the regular extruded snacks without the supplementation.

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