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Original article

Effect of extrusion conditions on the physicochemical properties of a snack made from purple rice (Hom Nil) and soybean flour blend

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Summary Soy flour was added at levels of 5%, 10%, and 15% of Hom Nil rice flour for extrusion at 190 °C barrel temperature and 350 rpm screw speed. The extruded snack qualities decreased inversely with soy flour. However, product qualities were considered to be optimised when soy flour at 5% was added. The effect of feed moisture content (15, 17, 19 g (100 g)$^{-1}$ wb), barrel temperature (150, 170, 190 °C) and screw speed (350, 400, 450 rpm) on physicochemical properties of the snack were then investigated. The physicochemical properties of the product including expansion ratio, density, water absorption index (WAI), water solubility index (WSI) and hardness were evaluated. All properties were related, as linear equations, in terms of feed moisture content, barrel temperature, screw speed with relative correlation (R^2) at 0.83–0.94. The snack properties along with consumer acceptance were all highest when the extruded condition were 15 g (100 g)$^{-1}$ wb feed moisture content, 170 °C of barrel temperature and 450 rpm of screw speed.

Keywords Extrusion, hom nil rice, physicochemical properties, single screw extruder, snack, soybean flour.

Introduction

Extrusion cooking is being used increasingly in the production of food products such as baby food, textured vegetable protein (TVP), breakfast cereals and snacks. The extrusion process is responsible for a number of product attributes. Physical properties and sensory attributes of an extruded product can vary considerably depending on operating conditions and properties of raw material (Liu *et al*., 2000). Small variations in operating conditions affect product quality (Desrumaux *et al*., 1999). Extrusion cooking can modify starches or other food materials to produce a variety of new and unique snack food products (Riaz, 2000). A wide range of raw ingredients can be selected and blended together to make numerous types of snacks. Snack products produced by extrusion process can be made from various types of cereals as a major raw material such as rice, corn, and wheat (Booth, 1990).

Rice flour is extensively used in the extrusion industry due to its suitable properties such as bland taste, white colour and digestibility (Kadan *et al*., 2003). Rice flour is used to manufacture products such as snack, puffed products, breakfast cereal, and fortified products and can be produced at a low cost using a single screw extruder (Riaz, 2000). However, the varieties of rice play an important role in determining the types and properties of extrusion products (Pan *et al*., 1992).

Purple rice called 'Hom Nil' (*Oryza sativa* L.) is reported to have high nutritional value and it provides some special characteristics that can be used as the raw material to produce snack by extruder. Among the special characteristics of this rice type, the foremost is its dark purple to almost black colour due to the pigments called anthocyanin and proanthocyanidin. Hom Nil rice contains 10–12.5% protein twice that of other common rice varieties, high antioxidant content and is rich in fiber and minerals (Sinin rice Company, 2004). Charunuch *et al*. (2003) reported that when soybean was added to rice flour, it improved texture, appearance and nutritional value of snack food.

The objective of this research was to develop an expanded snack product from a blend of Hom Nil rice and soybean flour using a single screw extruder. Additionally, the study describes changes in the physicochemical properties of the product with moisture content of feed, barrel temperature and screw speed of the extruder.

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Materials and methods

Hom Nil rice (*Oryza sativa* L.) was purchased from Organic Agricultural Learning Center, Lop Buri province, Thailand, ground, sieved (100 μm), vacuum sealed in polyethylene bags and stored at 4 °C. Soybean flour (full fat and 60% protein content), was purchased from the Royal Project Foundation, Doi Kham Food Product Co., Ltd, Thailand. Moisture content of both Hom Nil rice flour and soybean flour was determined by the method of AOAC (1990).

During the preliminary experiments, proportions of rice and soybean in the mixture were varied from 95:5, 90:10 and 85:15, by weight to observe expansion ratio, density and hardness. Moisture content of each mixture was adjusted to 15% by spraying the calculated volume of distilled water as fine mist. Samples were sealed in double-layers polyethylene bag and stored at 4 °C for 48 h. Before extrusion, the feed samples were warmed to 25 °C and moisture content was measured by the method of AOAC (1990). For further experiments, the suitable mixture was selected based on sensory score of the prepared snack by expert panelists.

Snack product from the mixture of rice and soybean flour was produced with a laboratory scale single screw extruder. Screw length per diameter (L/D), screw diameter and length were 12:1, 25 and 300 mm, respectively. Diameter of die hole and barrel were 2 and 25 mm, respectively. The extruder was composed of two sections, transition and die zone. The extruder barrel section was heated with band heater. The extrusion conditions were varied including feed moisture content, barrel temperature and screw speed. Feed moisture contents were 15, 17 and 19 g (100 g)$^{-1}$ wb. The barrel temperature at die zone was adjusted to the desired temperature of 150, 170 and 190 °C whereas the transition zone was fixed at 110 °C. Screw speed was adjusted at 350, 400 and 450 rpm. Feed rate was fixed at 20 g min^{-1}. Each condition of extrusion was brought to steady state before sampling. At steady barrel temperature and screw speed, the extrudate were cut manually into 8 cm long pieces and cooled at room temperature for 30 min. Samples were packed in polyethylene bags and stored at room temperature for analysis.

Expansion of extrudate was measured in terms of diameter, at three points on each piece, of the extruded product to the die diameter (Harper, 1981; Ding *et al.*, 2005, 2006; Stojceska *et al.*, 2008) by using a vernier caliper to measure the average thickness of extrudate. Expansion ratios were the average of ten randomly chosen pieces of extrudate for each replicate. The experiment was conducted in three replicates.

Individual cylindrical extrudate rods were weighed individually, the diameter and length were measured by using vernier caliper. Density of extrudates calculated according to the method of Alvarez-Martinez *et al.* (1988)

$$\text{Density}\,(\text{g cm}^{-3}) = 4m/Pid^2L$$

where m and L are rod mass (g) and length (cm) of cooled extrudate with diameter d (cm). The density values were calculated as average of ten measurements for each replicate and the experiment was done in triplicate.

Water absorption index (WAI) and water solubility index (WSI) of extrudates were determined according to the method developed by Anderson *et al.* (1969) for cereals. A suspension of 2.5 g of ground extrudate sample (100 mesh) was prepared in 25 mL distilled water at room temperature for 30 min by gently stirring during this period, and then centrifuged at 3000 rpm for 15 min. The supernatant was decanted carefully into an aluminium dish of known weight and the remaining gel or sediment was weighed. WAI was taken as the weight of gel after removal of the supernatant per unit weight of the ground sample. The supernatant liquid from the WAI test was dried to constant weight at 105 °C. WSI was equated to the weight of dry solid recovered by evaporating the supernatant as a percentage of dry solids in the initial dry sample (Ding *et al.*, 2005, 2006; Stojceska *et al.*, 2008).

The texture characteristics of extrudate were measured using a texture analyser (Stable Micro System TA., XT plus, Surrey, UK) fitted with a five-blades Kramer shear probe with the pre-test speed of 1.0 mm s^{-1}, test speed of 2.0 mm s^{-1} and post-test speed of 10.0 mm s^{-1}. Samples were placed across the width of the Kramer shear cell to cover the bottom of the cell in a single layer (Suknark *et al.*, 1997). A force–time curve was recorded and analysed to calculate the peak force. The peak force was chosen to represent the hardness of extrudate in Newton (Ding *et al.*, 2005). Ten randomly collected samples of each replicate were selected for texture measurement and the values are being reported in average.

The sensory test was conducted with thirty untrained panellists by 9-point hedonic scale (1 – extremely dislike to 9 – extremely like) in order to select the optimal condition of extrusion. Panellists were asked to evaluate the preference of the products, including appearance, colour, flavour, hardness and overall acceptability. Thirty panellists including fifteen females and fifteen males in the age between 23 and 30 years were the students of the Asian Institute of Technology, Thailand in the field of Food Engineering and Bioprocess Technology. Finally, a randomised complete block design (RCBD) was used to analyse the data.

A $3 \times 3 \times 3$ factorial design was used to investigate the effect of feed moisture content (15, 17 and 19 g (100 g)$^{-1}$ wb), barrel temperature (150, 170 and

190 °C) and screw speed (350, 400 and 450 rpm) on the physicochemical properties of extrudates. The data of different treatments were analysed using analysis of variance (ANOVA) at 0.05 significant level using SPSS version 17.0 program for Window®. Duncan's multiple range test (DMRT) was used to compare treatment if significant difference found at 0.05 significant level.

Results and discussion

We found that soybean flour can improve puffed ability and texture of extrudate and also provide the product with smooth surface. Soybean flour significantly affected expansion ratio, density and hardness of snacks. Snack produced from Hom Nil rice with 5% soybean had the highest expansion ratio and the lowest density and hardness. Increasing the level of soybean flour in the mixture significantly reduced the expansion ratio and increased the density and hardness of the extrudates. The addition of protein to starchy extrudates reduced the expansion of products by reducing the extensibility of the starch polymer during its expansion at the die exit (Chiyakul *et al.*, 2009).

The mixture of Hom Nil rice with 5% soybean received the highest score for appearance, hardness and overall acceptance of snack samples. This implied that panellists preferred snack from Hom Nil rice with soybean mixed 5% that provided the highest expansion ratio with the lowest density and hardness. Therefore, Hom Nil rice with 5% soybean was used as the feed mixture to investigate effect of extrusion conditions on the physicochemical properties of the product.

Effect of extrusion conditions on expansion ratio of extrudates

Feed moisture content had a significant effect on expansion of snacks ($P < 0.05$). Expansion ratios tended to decrease inversely with increasing feed moisture content. For examples, increasing feed moisture content at the range 15–19 g (100 g)$^{-1}$ wb caused a decrease in expansion ratio in a range of 7.7–10.9% at all barrel temperatures with 350 rpm screw speed (Table 1). The high dependence of expansion on feed moisture would reflect its influence on elasticity characteristics of the starch-based material. Increased feed moisture content during extrusion may reduce the elasticity of the dough through plasticisation of the melt, resulting in reduced gelatinisation and therefore decreasing the expansion of extrudate (Ding *et al.*, 2006). The expansion of extrudate depends on the pressure difference between the die and the atmosphere as well as the ability of the exiting product to sustain expansion which relate to viscosity of feed material. High feed moisture content usually provides less viscosity than lower moisture content. Thus, the pressure difference is higher for low feed moisture content that consequently provides a higher expansion of extrudate (Harper, 1981; Suknark *et al.*, 1997). Moreover, Liu *et al.* (2000) reported that increased feed moisture content reduced friction between the feed material, screw and barrel and also have a negative impact on the starch gelatinisation and reduce the product expansion.

Table 1 Effect of feed moisture content, barrel temperature and screw speed on expansion ratio of extrudates

Feed MC (g (100 g)$^{-1}$ wb)	Barrel temperature (°C)	Screw speed (rpm) 350	400	450
15	150	$2.74^{bc}_{B} \pm 0.04$	$2.61^{b}_{A} \pm 0.05$	$2.55^{b}_{A} \pm 0.07$
	170	$3.04^{e}_{B} \pm 0.04$	$2.91^{e}_{A} \pm 0.02$	$2.88^{e}_{A} \pm 0.08$
	190	$3.21^{f} \pm 0.15$	$3.16^{g} \pm 0.04$	$3.05^{f} \pm 0.04$
17	150	$2.67^{b}_{B} \pm 0.04$	$2.53^{a}_{A} \pm 0.02$	$2.49^{ab}_{A} \pm 0.04$
	170	$2.98^{de}_{B} \pm 0.09$	$2.82^{d}_{A} \pm 0.05$	$2.79^{d}_{A} \pm 0.04$
	190	$3.19^{f}_{B} \pm 0.04$	$3.08^{f}_{A} \pm 0.04$	$3.03^{f}_{A} \pm 0.03$
19	150	$2.53^{a} \pm 0.08$	$2.49^{a} \pm 0.02$	$2.43^{a} \pm 0.01$
	170	$2.75^{bc}_{B} \pm 0.04$	$2.69^{c}_{A} \pm 0.02$	$2.65^{c}_{A} \pm 0.03$
	190	$2.86^{cd} \pm 0.03$	$2.82^{d} \pm 0.06$	$2.84^{de} \pm 0.03$

Sample means with the different superscript letter in common among columns or subscript letter in common among rows are significantly different ($P < 0.05$). Sample means with no subscript of capital letter in the same row are not significantly different ($P < 0.05$).

Increased barrel temperature led to a sharp increase in expansion ratio value at all moisture content and screw speed ($P < 0.05$). Increasing barrel temperature from 150 to 190 °C resulted in a range of 13–21.7% increase in expansion ratio value of snacks at all levels of feed moisture content and screw speed (Fig. 1). Expansion was found to be depending on barrel temperature and also feed moisture content.

Screw speed was observed to have a slight effect on expansion ratio of snacks. Increased screw speed caused a slight decrease in expansion ratio. Launay & Lisch (1983) reported that the higher shear resulting from the higher screw speed reduces the melt viscosity of the feed material resulting in decreased expansion ratio.

Effect of extrusion conditions on density of extrudates

The density of snacks increased directly with feed moisture content at all barrel temperatures and screw speeds ($P < 0.05$). Increasing feed moisture content from 15 to 19 g (100 g)$^{-1}$ wb resulted in 31.8% increase in density value of snack at 150 °C barrel temperature with 350 rpm of screw speed (Table 2). Moisture content of feed has been found to be the main factor affecting density and expansion of extrudates (Ding *et al.*, 2005). Increased feed moisture content during extrusion reduced expansion ratio but increased density of extrudates because feed moisture had an influence on

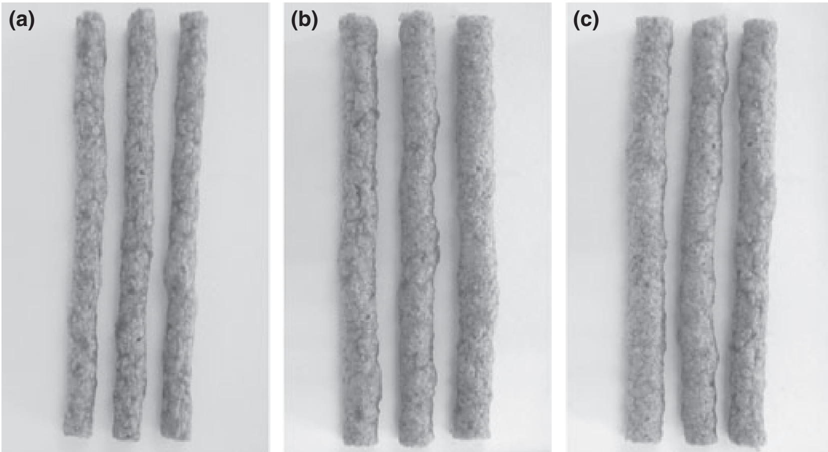

Figure 1 Hom Nil rice and soybean snack at different extrusion conditions (a) 15% feed MC at 150 °C and 450 rpm (b) 15% feed MC at 170 °C and 450 rpm (c) 15% feed MC at 190 °C and 450 rpm.

Table 2 Effect of feed moisture content, barrel temperature and screw speed on density (g cm^{-3}) of extrudates

Feed MC (g (100 g)$^{-1}$ wb)	Barrel temperature (°C)	Screw speed (rpm) 350	400	450
15	150	$0.22^{cd} \pm 0.01$	$0.22^{d} \pm 0.01$	$0.22^{de} \pm 0.02$
	170	$0.15^{ab} \pm 0.01$	$0.15^{a} \pm 0.00$	$0.16^{a} \pm 0.00$
	190	$0.13^{a} \pm 0.01$	$0.14^{ab} \pm 0.01$	$0.14^{ab} \pm 0.00$
17	150	$0.25^{d} \pm 0.03$	$0.23^{d} \pm 0.01$	$0.24^{ef} \pm 0.01$
	170	$0.21^{c} \pm 0.01$	$0.20^{c} \pm 0.00$	$0.19^{c} \pm 0.01$
	190	$0.17^{b} \pm 0.01$	$0.17^{b} \pm 0.01$	$0.16^{b} \pm 0.00$
19	150	$0.29^{e} \pm 0.02$	$0.28^{f} \pm 0.01$	$0.25^{f} \pm 0.00$
	170	$0.25^{d} \pm 0.01$	$0.26^{e} \pm 0.01$	$0.24^{f} \pm 0.01$
	190	$0.24^{d} \pm 0.01$	$0.22^{d} \pm 0.02$	$0.21^{d} \pm 0.01$

Sample means with the different superscript letter in common among columns or subscript letter in common among rows are significantly different ($P < 0.05$). Sample means with no subscript of capital letter in the same row are not significantly different ($P < 0.05$).

the reduction of elasticity characteristics and gelatinisation of the starch-based materials (Fletcher *et al.*, 1985). Many studies on starch-based snack foods have reported an inverse relation between feed moisture content and the density of extrudates (Ding *et al.*, 2005; Pansawat *et al.*, 2008; Chaiyakul *et al.*, 2009).

High barrel temperature led to decrease in density of extrudates ($P < 0.05$). Increasing barrel temperature from 150 to 190 °C resulted in 40.9% decrease in density value of snack at 15 g (100 g)$^{-1}$ wb of feed moisture content with 350 rpm of screw speed and 36.4% decrease in density value at 15% feed moisture content with 400 rpm and 450 rpm of screw speed. Product density was closely related with expansion ratio. An increase in barrel temperature would increase the degree of superheating of water promoting bubble formation and also a decrease in melt viscosity leading to increased expansion that caused a decrease in density of extrudates (Fletcher *et al.*, 1985). This result was in agreement with the study on rice-based expanded snack by Ding *et al.* (2005). However, screw speed was found to have no significant effect on density. This might be due to the range of screw speed varied for this study which was not enough to cause significant effect.

Effect of extrusion conditions on WAI of extrudates

WAI of snack changed directly with feed moisture content ($P < 0.05$). For instance, increasing feed moisture content from 15 to 19 g (100 g)$^{-1}$ wb resulted in 13% increase in WAI of snack at 150 °C barrel temperature with 350 rpm of screw speed (Table 3). Similar trend has been reported by Ding *et al.* (2005) that increasing feed moisture content significantly increased the WAI of rice-based expanded snack. The WAI value increased because higher feed moisture content resulted in a lower degree of starch gelatinisa-

Table 3 Effect of feed moisture content, barrel temperature and screw speed on WAI (g g^{-1}) of extrudates

Feed MC (g (100 g)$^{-1}$ wb)	Barrel temperature (°C)	Screw speed (rpm) 350	400	450
15	150	$3.39^{a}{}_{B} \pm 0.01$	$3.38^{a}{}_{B} \pm 0.01$	$3.24^{a}{}_{A} \pm 0.01$
	170	$3.50^{b} \pm 0.03$	$3.44^{a} \pm 0.04$	$3.45^{b} \pm 0.04$
	190	$3.86^{de}{}_{B} \pm 0.05$	$3.78^{cd}{}_{A} \pm 0.03$	$3.81^{d}{}_{AB} \pm 0.02$
17	150	$3.69^{c}{}_{B} \pm 0.03$	$3.67^{b}{}_{B} \pm 0.05$	$3.56^{c}{}_{A} \pm 0.07$
	170	$3.73^{c}{}_{B} \pm 0.02$	$3.73^{bc}{}_{B} \pm 0.03$	$3.62^{c}{}_{A} \pm 0.02$
	190	$3.90^{e} \pm 0.07$	$3.82^{d} \pm 0.07$	$3.84^{d} \pm 0.02$
19	150	$3.83^{d} \pm 0.04$	$3.81^{d} \pm 0.05$	$3.85^{d} \pm 0.04$
	170	$3.89^{de} \pm 0.02$	$3.88^{d} \pm 0.03$	$3.92^{e} \pm 0.05$
	190	$3.97^{f} \pm 0.01$	$3.95^{f} \pm 0.03$	$3.95^{e} \pm 0.04$

Sample means with the different superscript letter in common among columns or subscript letter in common among rows are significantly different ($P < 0.05$). Sample means with no subscript of capital letter in the same row are not significantly different ($P < 0.05$).

tion during extrusion process that caused an increase in water absorption ability of starch granule and undamaged polymer chains (Guha *et al.*, 1997; Panuwat, 2004).

Changing barrel temperature from 150 to 190 °C increased the WAI value ($P < 0.05$). For 15 g (100 g)$^{-1}$ wb of feed moisture, increasing barrel temperature from 150 to 190 °C was observed to cause a range of 11.8–17.6% increase in WAI of snack while increasing barrel temperature caused a slight increase (3.7–7.9%) in WAI for 17% and 19% feed moisture content at all levels of screw speed. WAI generally increased along with the increase in extrusion temperature. It had a maximum peak at a certain temperature after which it decreased (Sacchetti *et al.*, 2004). Screw speed was observed to have a little effect on WAI. WAI values were nearly constant when screw speed increased.

Effect of extrusion conditions on WSI of extrudates

The WSI of extrudates was affected by feed moisture content ($P < 0.05$). Increasing feed moisture content progressively decreased the WSI of snack. Increasing feed moisture content from 15 to 19 g (100 g)$^{-1}$ wb resulted in a range of 26.2–34.1% decrease in WSI of snack at all levels of barrel temperature and screw speed (Table 4). Higher feed moisture content provided the extrudate with lower WSI because lower starch degradation occurred in the higher feed moisture content condition that provided higher material flow rate inside the barrel and caused a lower in shear rate and residence time (Panuwat, 2004). This result is consistent with previous studies on extrudate from rice flour (Ding *et al.*, 2005; Lei *et al.*, 2005).

Changing the levels of barrel temperature from 150 to 190 °C had a significant effect on WSI of the snack ($P < 0.05$). WSI value increased with increasing barrel temperature. For example, increasing barrel temperature from barrel temperature from 150 to 190 °C was observed to cause 16.4% increasing in WAI of snack for 17% feed moisture at 400 rpm screw speed. This observation was the same with the study on rice-based expanded snack of Ding *et al.* (2005). Increasing barrel temperature which resulted in increased product temperature and degradation of starch would increase WSI (Lei *et al.*, 2005). Because WSI also depends on the quantity of soluble materials, soluble starch increased with increasing extrusion temperature due to increasing in starch degradation or the extent of gelatinisation (Guha *et al.*, 1997). WSI often used as an indicator of degradation of molecule component which is the amount of soluble polysaccharide released from the starch component after extrusion which measures the degree of starch conversion during extrusion (Kirby *et al.*, 1988; Ding *et al.*, 2005).

Increasing screw speed slightly increased WSI value of extrudate. This is agree with the study of Lie *et al.* (2005) which reported that increasing screw speed from 350 to 450 rpm increased WSI of exrudate from rice flour. WSI of extrudates increased directly with screw speed because the higher mechanical shear caused more starch degradation (Mezreb *et al.*, 2003).

Table 4 Effect of feed moisture content, barrel temperature and screw speed on WSI (%) of extrudates

Feed MC (g (100 g)$^{-1}$ wb)	Barrel temperature (°C)	Screw speed (rpm) 350	400	450
15	150	$19.84^{e}_{A} \pm 0.23$	$20.64^{f}_{B} \pm 0.25$	$21.31^{f}_{C} \pm 0.21$
	170	$20.46^{f}_{A} \pm 0.33$	$20.81^{f}_{A} \pm 0.14$	$21.43^{fg}_{B} \pm 0.29$
	190	$21.09^{g}_{A} \pm 0.24$	$21.60^{g}_{AB} \pm 0.39$	$21.77^{fg}_{B} \pm 0.20$
17	150	$15.94^{c}_{B} \pm 0.20$	$16.15^{c}_{A} \pm 0.23$	$16.90^{c}_{C} \pm 0.23$
	170	$17.13^{d}_{A} \pm 0.14$	$17.06^{d}_{A} \pm 0.15$	$18.05^{d}_{B} \pm 0.19$
	190	$17.39^{d}_{A} \pm 0.45$	$18.79^{e}_{B} \pm 0.17$	$19.29^{e}_{B} \pm 0.16$
19	150	$13.46^{a}_{A} \pm 0.25$	$13.83^{a}_{A} \pm 0.23$	$14.05^{a}_{B} \pm 0.29$
	170	$13.84^{b}_{B} \pm 0.31$	$13.95^{a}_{A} \pm 0.16$	$14.24^{a}_{B} \pm 0.30$
	190	$14.69^{b}_{A} \pm 0.69$	$14.90^{b}_{A} \pm 0.52$	$16.07^{b}_{B} \pm 0.24$

Sample means with the different superscript letter in common among columns or subscript letter in common among rows are significantly different ($P < 0.05$). Sample means with no subscript of capital letter in the same row are not significantly different ($P < 0.05$).

Effect of extrusion conditions on hardness of extrudates

Hardness of extrudates was affected by feed moisture content ($P < 0.05$). Increasing feed moisture content increased the hardness of snack. Increasing feed moisture content from 15 to 19 g (100 g)$^{-1}$ wb resulted in a range of 29.7–51.8% decrease in hardness of snack at all levels of barrel temperature and screw speed (Table 5). Previous studies also reported that the hardness of extrudate increased as the feed moisture content increased (Ding *et al.*, 2005, 2006). This might be due to the increase in feed moisture content reduced expansion and provided a dense product that required the higher force to break the sample (Liu *et al.*, 2000). The lowest hardness (307.3 N) obtained from extrusion at 15 g (100 g)$^{-1}$ wb of feed moisture content and 190 °C which were the lowest feed moisture content and the highest barrel temperature.

The hardness of snack was significantly influenced by barrel temperature. Increasing barrel temperature decreased hardness of extrudates. For instance, increasing barrel temperature from 150 to 190 °C was observed to cause a range of 12.2–18% decreasing in hardness of snack for 15 g (100 g)$^{-1}$ wb of feed moisture content at all levels of screw speed. Increasing barrel temperature decreased melt viscosity which provided the low density products with small and thin cell walls resulted in the lower hardness of extrudate. However, barrel temperature and feed moisture content also had an effect on hardness (Ding *et al.*, 2005).

Table 5 Effect of feed moisture content, barrel temperature and screw speed on hardness (*N*) of extrudates

Feed MC (g (100 g)$^{-1}$ wb)	Barrel temperature (°C)	Screw speed (rpm)		
		350	400	450
15	150	$405.57^{c}_{B} \pm 2.21$	$376.85^{c}_{A} \pm 5.89$	$374.38^{b}_{A} \pm 10.94$
	170	$377.21^{b} \pm 11.59$	$358.65^{b} \pm 7.79$	$360.29^{b} \pm 8.41$
	190	$332.60^{a}_{B} \pm 5.25$	$331.05^{a}_{B} \pm 7.02$	$307.31^{a}_{A} \pm 4.99$
17	150	$437.63^{d}_{B} \pm 4.07$	$422.85^{e}_{A} \pm 4.88$	$424.47^{d}_{A} \pm 5.96$
	170	$425.72^{d} \pm 8.70$	$417.22^{e} \pm 11.84$	$404.13^{c} \pm 12.97$
	190	$406.96^{c}_{B} \pm 8.79$	$397.96^{d}_{B} \pm 10.58$	$368.95^{b}_{A} \pm 7.83$
19	150	$525.90^{f}_{B} \pm 6.37$	$513.22^{g}_{B} \pm 8.14$	$506.43^{g}_{A} \pm 2.73$
	170	$517.63^{f}_{B} \pm 2.47$	$505.16^{g}_{AB} \pm 12.30$	$489.46^{f}_{A} \pm 10.49$
	190	$498.23^{e} \pm 11.24$	$484.51^{f} \pm 17.29$	$466.36^{e} \pm 9.04$

Sample means with the different superscript letter in common among columns or subscript letter in common among rows are significantly different ($P < 0.05$). Sample means with no subscript of capital letter in the same row are not significantly different ($P < 0.05$).

Screw speed was found to have a slight effect on hardness of snacks. It was observed that increased screw speed caused a slight decrease in hardness. The study of Liu *et al*. (2000) stated that a higher screw speed may have decreased the hardness of extrudate by increasing product temperature, which usually leads to a higher expansion and a lower density.

The summary of equations analysed by multiple linear regressions describing the relationship of the extrusion variables on the product physicochemical properties and the relationship among the product physicochemical properties are shown in Tables 6 and 7. Only first order regression equations were obtained as data of the extrusion parameters was in limited range.

Effect of extrusion conditions on sensory evaluation of extrudates

The results of sensory evaluation of snacks by 9-point hedonic scale indicated that Hom Nil rice and soybean snack, extruded with 15% feed moisture content at 170° barrel temperature and 450 rpm screw speed, had the highest score of overall acceptance (7.30). This score indicates that panelist preferred the sample as 'like moderately' to 'like very much' and also the preferred

Table 7 Multiple linear regression equations for physicochemical properties of products

Response	Equation
Expansion ratio (ER)	$ER = 0.8133 - 3.0523D + 0.5728WAI + 0.0281WSI$
	$R^2_a = 0.7720$ SEE = 0.1109
Density (D)	$D = 0.2970 - 0.0946ER + 0.0004H$
	$R^2_a = 0.8674$ SEE = 0.0168
Water absorption index (WAI)	$WAI = 4.2782 + 0.4621ER - 1.7188D - 0.0853WSI$
	$R^2_a = 0.7617$ SEE = 0.0996
Water solubility index (WSI)	$WSI = 40.7464 + 2.2061ER - 4.2690WAI - 0.0318H$
	$R^2_a = 0.9508$ SEE = 0.6361
Hardness (H)	$H = 659.5856 + 313.4657D - 17.1138WSI$
	$R^2_a = 0.9293$ SEE = 16.9128

R^2_a, adjusted R^2; SEE, standard error of estimation.

Table 6 Multiple linear regression equations for extrusion conditions and physicochemical properties of products

Response	Equation
Expansion ratio (ER)	$ER = -1.8905 + 0.1609M + 0.0323T - 0.0011MT - 3.7 \times 10^{-7}MTS$
	$R^2_a = 0.8395$ SEE = 0.0920
Density (D)	$D = 0.7724 - 0.0163M - 0.0055T + 0.0002MT$
	$R^2_a = 0.8496$ SEE = 0.0190
Water absorption index (WAI)	$WAI = -5.3743 + 0.4789M + 0.0446T - 0.0022MT - 3.1 \times 10^{-5}MS$
	$R^2_a = 0.9072$ SEE = 0.0621
Water solubility index (WSI)	$WSI = 45.8695 - 1.9669M + 4.5 \times 10^{-6}MTS$
	$R^2_a = 0.9731$ SEE = 0.4709
Hardness (H)	$H = 609.3348 - 4.0587T + 0.2094MT - 0.0015TS$
	$R^2_a = 0.9582$ SEE = 13.0091

Where M is the moisture content, T is the barrel temperature, S is the screw speed, R^2_a is the adjusted R^2 and SEE is the standard error of estimation.

Table 8 Sensory evaluation by 9-point hedonic scale of Hom Nil rice and soybean snack at different extrusion conditions

Extrusion conditions	Appearance	Colour	Flavour	Hardness	Overall acceptance
15% 150°C 350 rpm	6.00 ± 1.21^{cd}	6.00 ± 0.86^{def}	5.55 ± 1.10^{bc}	6.15 ± 1.23^{cde}	6.00 ± 0.80^{d}
15% 150°C 400 rpm	6.20 ± 1.06^{def}	6.10 ± 1.29^{ef}	5.85 ± 1.09^{c}	6.30 ± 1.03^{def}	6.10 ± 0.97^{d}
15% 150°C 450 rpm	5.85 ± 1.09^{cd}	6.00 ± 0.92^{def}	5.85 ± 1.04^{c}	5.60 ± 1.35^{c}	5.90 ± 0.97^{d}
15% 170°C 350 rpm	6.30 ± 1.17^{defg}	6.35 ± 1.27^{efg}	5.55 ± 0.89^{bc}	6.30 ± 1.30^{def}	6.20 ± 1.15^{de}
15% 170°C 400 rpm	6.75 ± 1.07^{fgh}	6.30 ± 1.26^{efg}	5.65 ± 0.81^{c}	6.95 ± 0.94^{fgh}	6.70 ± 0.98^{ef}
15% 170°C 450 rpm	7.00 ± 0.97^{h}	6.75 ± 0.79^{g}	6.65 ± 1.09^{d}	7.35 ± 0.82^{h}	7.30 ± 0.92^{g}
15% 190°C 350 rpm	6.60 ± 0.88^{efgh}	6.20 ± 1.32^{defg}	5.75 ± 0.97^{c}	6.55 ± 1.40^{defg}	6.40 ± 1.39^{def}
15% 190°C 400 rpm	6.90 ± 1.02^{gh}	6.60 ± 0.94^{fg}	6.65 ± 1.04^{d}	7.20 ± 1.01^{gh}	6.85 ± 0.67^{fg}
15% 190°C 450 rpm	6.90 ± 1.16^{gh}	6.80 ± 1.06^{g}	6.75 ± 0.97^{d}	7.20 ± 0.89^{gh}	6.90 ± 0.72^{fg}
17% 150°C 350 rpm	4.60 ± 1.00^{a}	4.55 ± 1.40^{a}	4.80 ± 1.74^{a}	3.85 ± 0.99^{a}	3.90 ± 0.79^{a}
17% 150°C 400 rpm	5.00 ± 1.03^{ab}	4.90 ± 1.45^{ab}	4.90 ± 1.25^{ab}	4.55 ± 1.00^{b}	4.25 ± 0.72^{ab}
17% 150°C 450 rpm	5.00 ± 1.26^{ab}	4.95 ± 1.19^{ab}	4.90 ± 0.91^{ab}	4.80 ± 1.28^{b}	4.70 ± 1.08^{bc}
17% 170°C 350 rpm	5.15 ± 1.04^{ab}	5.70 ± 1.13^{cde}	5.35 ± 1.78^{abc}	4.80 ± 1.15^{b}	4.95 ± 1.19^{c}
17% 170°C 400 rpm	5.40 ± 1.00^{bc}	5.35 ± 1.18^{bc}	5.35 ± 0.99^{abc}	4.55 ± 1.05^{b}	4.75 ± 1.07^{bc}
17% 170°C 450 rpm	6.10 ± 1.29^{de}	5.60 ± 1.23^{cd}	5.80 ± 1.06^{c}	5.90 ± 1.25^{cd}	6.00 ± 1.21^{d}
17% 190°C 350 rpm	5.95 ± 1.15^{cd}	5.80 ± 0.95^{cde}	6.00 ± 1.34^{c}	6.15 ± 1.09^{cde}	5.85 ± 1.35^{d}
17% 190°C 400 rpm	6.00 ± 1.45^{de}	5.80 ± 1.36^{cde}	5.65 ± 1.23^{c}	6.65 ± 0.99^{efg}	6.20 ± 1.44^{de}
17% 190°C 450 rpm	6.45 ± 1.36^{defgh}	5.75 ± 1.21^{cde}	5.90 ± 1.29^{c}	6.05 ± 1.00^{cde}	6.10 ± 1.02^{d}

Sample means with at least one superscript letter in common among columns are significantly different at $\alpha = 0.05$.

Table 9 Correlation coefficients between physical properties and sensory attributes for extrudates

	Density	Hardness	Hardness score	Overall acceptance
Density	1			
Hardness	0.804*	1		
Hardness score	−0.810*	−0.831*	1	
Overall acceptance	−0.801*	−0.838*	0.982*	1

*Correlation is significant at the 0.01 level (two-tailed).

sample obtained the highest preference score for the hardness and appearance (Table 8). Therefore, this condition can be the optimal extrusion condition for producing Hom Nil rice and soybean snack.

A correlation analysis between physical properties of extrudates and sensory attributes revealed that expansion ratio was positively correlated with hardness score and overall acceptance of the products ($P < 0.05$) (Table 9) while density was negatively correlated with these sensory scores ($P < 0.01$) with correlation coefficient of −0.810 and −0.801, respectively. This could be associated to the previous result that the higher expanded extrudates with lower density which have larger cells and thinner cell walls resulting in a lower hardness product would obtain high liking score of hardness and overall acceptance. In addition, the instrumental hardness was negatively correlated with hedonic scale hardness score ($r = -0.83$) and overall acceptance ($r = -0.84$) from sensory evaluation. It also indicated that the low hardness products would obtain high preferring score of hardness and overall acceptance from panellists. Moreover, the hardness score showed a high positive correlation with overall acceptance score ($r = 0.98$). It implied that the panellists judged the overall acceptance mainly by hardness of the products. Thus, the textural characteristics of snack food are among the most important index for product acceptability.

Conclusion

Feed moisture content and barrel temperature were the most importance factors that effect on physicochemical properties of products. Screw speed had a slight effect on all properties of products. Increasing feed moisture content resulted in extrudates with a lower expansion ratio, higher density, higher WAI, lower WSI and higher hardness. Increasing temperature caused an increase in expansion ratio, WSI and WAI but caused a decrease in density and hardness. The result of sensory evaluation showed that Hom Nil rice and soybean snack produced from 15 g $(100)^{-1}$ wb feed MC at 170 °C barrel temperature and 450 rpm screw speed was the optimum extrusion condition as this condition obtained the highest hedonic score of appearance, hardness and overall acceptance from panellists.

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