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Effect of Hom Nil rice flour moisture content, barrel temperature and screw speed of a single screw extruder on snack properties

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Abstract

Moisture contents of Hom Nil rice flour for fixed extrusion conditions, 120 and 80°C of die and transition zone temperature of barrel, respectively and 250 rpm screw speed, were varied at 13, 15 and 17%. Physicochemical and sensory properties of the product were evaluated. The 15% moisture content of rice flour caused the optimum properties of extrudate. The effects of die-zone barrel temperature (120, 140, 160°C) and screw speed (150, 200, 250 rpm) on extrudate qualities were then investigated. Increasing temperature and screw speed caused an increase in expansion ratio and a decrease in density and hardness of extrudate. The values of expansion ratio, density, water absorption index (WAI), water solubility index (WSI), hardness and air-cell area varied from 2.5-3.6, 0.2-0.5 g/cm^3, 5.3-6.8 g water/g sample, 4.00-11.0%, 265-320 g (force), and 20-38%, respectively. While, the overall acceptance score from sensory evaluation was in range from 2.3 to 7.9. The Hom Nil rice snack, produced at the condition: 120 and 80°C of die and transition zone temperature of barrel, respectively; and 250 rpm screw speed, had the highest qualities, indicated by physicochemical and consumer determinations.

Introduction

Hom Nil rice is a special long grain strain that has been developed from black glutinous rice from China called Hin Bao (Sinin rice Company, 2004). A special characteristic is its dark purple to almost black color due to the presence of anthocyanin and proanthocyanidin pigments which are also antioxidants. Indeed its antioxidant content is about seven times higher than that of common brown rice. Moreover, its protein content is about twice that of other common rice (Chrispeels and David, 1994). These unique attributes and nutritional value make Hom Nil rice as an attractive source material for the production of healthy snack products through extrusion processing. The processing is increasingly applied to produce many types of food products such as baby food, textured vegetable protein, breakfast cereals and snacks because of its versatility and product quality. Ding *et al.* (2005) found that an elevation in die-zone barrel temperature in the range of 100-140ºC increased the expansion, WSI, and crispness of expanded rice-based snacks but reduced product density. Both the WAI and WSI of extruded rice flour also increased with the die-zone temperature of barrel (Kadan *et al*., 2003; Guha and Ali, 2006). Guha *et al.* (1997) reported that an increase in screw speeds at 200-300 rpm reduced the bulk density of extrudates from rice flour. The combination of extrusion conditions at high temperature and screw speed provided the product with low density. Pansawat *et al*. (2008) found that an increased screw speed from 150 to 250 rpm decreased the radial expansion of rice-based snack containing fish powder, while increased screw speed over 250 rpm increased the radial expansion. However, Ding *et al*. (2005) reported that screw speed had no significant effect on the physicochemical properties of expanded rice-based snacks. For expanded wheat-based snack, the WSI of a product increased with the die-zone barrel temperature while the density, WAI and hardness of the product were inversely affected (Ding *et al*., 2006). In addition, an increase in screw speed caused a slight reduction of density and hardness of expanded wheat-based snacks (Ding *et al*., 2006) and had a slight effect on WAI and WSI of cassava starch mixed with cassava bran when the screw speed was increased from 120 to 180 rpm (Hashimoto and Grossmann, 2003). Giri and Bandyopadhyay (2000) also reported that the

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expansion ratio and bulk density of a fish muscle-rice flour blend by using single screw extruder, were most influenced by barrel temperature For other products, such as an extruded oat-corn puff, screw speed had no significant effect on the expansion ratio and bulk density of extrudates. This might be due to high lipid content in oat flour, which resulted in a lubricant effect. However, increasing screw speed resulted in an increase in expansion ratio and a decrease in bulk density of the products which added corn flour (Liu *et al.*, 2000).The feed moisture content was also found to have the most significant influence on the properties of expanded rice-based snacks through the extrusion process (Ding *et al.*, 2005). Suksomboon *et al*. (2011) produced Hom Nil rice snack mixed with 5% soy flour, using single screw extrusion by varying feed moisture content, die-zone barrel temperature and screw speed at 15, 17 and 19%; 150, 170 and 190ºC; and 350, 400 and 450 rpm, respectively. The results indicated that die-zone barrel temperature was the most important factor effecting on properties of products, while screw speed only had a minor influence on all the properties of products. An increase in the die-zone barrel temperature caused an increase in the expansion ratio, WSI and WAI but also caused a decrease in density and hardness. The mixed Hom Nil rice and soybean snack, produced from 15% feed moisture content, at 170 and 110ºC die and transition zone barrel temperature, respectively and at 450 rpm screw speed, had the optimum qualities. The extrudate, produced from these conditions received the highest hedonic score of appearance, hardness and overall acceptance by panelists. However, soybean is one of the allergic foods. About 1–6% of infants are affected by soybean, while 2–4% of adults are suffered from soybean allergy with a variety of clinical symptoms (Herian *et al*., 1990; Tryphonas *et al.*, 2003). Therefore, a nutritionally and non-allergic extruded rice snack should be developed. However, the single screw extruder of Sawardsuk (2007) in laboratory must operate at a large amount of raw material, approximately 3 kg and the uncertain temperature of die barrel temperature was also always detected. For these reasons, a laboratory single screw extruder should also be developed in this experiment. The objectives of this research were to develop a laboratory single screw extruder and investigate the effects of Hom Nil rice flour moisture content, die-zone barrel temperature and screw speed of the extruder on the physicochemical and sensory properties of product.

Materials and Methods

Preparation of raw materials

Hom Nil rice was purchased from the Organic Agricultural Learning Center, Lop Buri province, Thailand. It was ground by pin mill at the Institute of Food Research and Product Development, Kasetsart University, Bangkok, Thailand, and the powder was then sifted through a 80 mesh screen. The flour was proximate analysis by AOAC (1990) method. For extrusion process, a calculated volume of distilled water was added to feed material to the desired level of moisture content by spraying. The samples were then sealed in double-layer polyethylene bags and stored for 48 h at 4ºC to allow maximum water absorption by flour (Suksomboon *et al*., 2011).

Development of a laboratory single screw extruder

We modified a conventional single screw extruder to accommodate larger samples, at least 3 kg of flour, and to improve operation and maintenance. Another concern with Sawardsuk (2007) was that machine caused burnt product during extrusion due to uncertain temperature levels. The extruders used to produce direct expanded snack products normally have a short screw length to provide high-shear stress process, and a typical screw speed applied to produce expanded snack products was 300-400 rpm (Booth 1990). The screw configuration and speed were important aspects that responsible for an increase in shear. The screw speed of our laboratory single screw extruder, was increased by decreasing the length per diameter ratio (L:D), as well as decreasing the pitch length and flight height of screw to achieve high-shear and enhance puffing of extrudate. The flight height of the screw was gradually decreased with constant pitch. The barrel design was the same as Sawardsuk's extruder except it was provided with band heaters (220 Volt and 550 Watt) for only two zones, transition and die. The feeding zone was mainly for feed mixing as heating was not necessary. The modified extruder was convenient to set up and required a smaller sample size only a minimum of 200 g to operate. The barrel and screw were made from stainless steel type 304. The barrel diameter and screw length were 25 mm and 610 mm, respectively. The extruder screw was driven by a 5 HP electrical motor (SEMCO, Germany), with a maximum speed of about 400 rpm and a 3 mm diameter die opening. The feed screw was also made of the same type of stainless steel and driven by a DC motor. Cutter device was set at the die and DC motor was used to rotate the knife. This extruder had the devices to control and indicate barrel temperature at the transition and die zone, the screw speed of the extruder, and the speed of the feed screw.

Testing performance of extruder

The modified single screw extruder was tested with Hom Nil rice flour at 15% moisture content. Feed rate was fixed at 20 g/min. It was operated at a screw speed of 300 rpm with a barrel temperature of 80 and 160°C at the transition and die zones, respectively. Temperature profile of extruder was measured at the wall of transition and die zones by thermocouples. The process at this condition was run for 20 min to check the temperature profile during extrusion. Temperature was monitored and recorded at 5 second intervals. The extruder output was measured by collecting a sample of extrudate for 1 min, which was weighed after cooling at room temperature (28-30°C) for 30 min. Extrudate mass flow rate was expressed as kg/h.

Preparation of extruded Hom Nil rice snack

Hom Nil rice flour moisture content varied at levels of 13, 15 and 17%, respectively. While the other extrusion conditions were fixed at a 20 g/min feed rate, 120 and 80°C die and transition zone temperature, respectively and 250 rpm of screw speed. The optimum feed moisture content was selected for the next experiment. Then, the effects of extrusion conditions, die-zone temperatures of 120, 140 and 160°C and screw speeds of 150, 200 and 250 rpm, on physicochemical and sensory properties of Hom Nil rice snack were investigated.

Analysis of physicochemical properties

Extrudate expansion was measured as a diameter of extruded product to die diameter (Ding *et al.*, 2005). Expansion ratio was determined using a vernier caliper to measure the average thickness of extrudates. Expansion ratio values were recorded as the average of 10 randomly chosen pieces of extrudate from each replicate.

Density of each extrudate was measured according to the equation described by Alvarez-Martinez *et al.* (1988).

$$\text{density (g/cm}^3\text{)} = \frac{4M}{¶D^2L}$$

M and L represent the mass (g) and length (cm) of cooled extrudate, as well as diameter (cm). The density values were the average of 10 measurements for each replicate.

A ground extrudate sample of 2.5 g (80 mesh) was suspended in 25 ml of distilled water at room temperature for 30 min. It was gently stirred during this period, and then centrifuged at 3000 g for 15 min. The supernatant was carefully decanted into an evaporating dish and the remaining gel or sediment was weighted. WAI was the weight of gel obtained after removal of the supernatant per unit weight of original dry solids. The supernatant liquid from the WAI test was poured into an aluminum dish and dried at 105°C to constant weight. WSI was expressed as the weight of dry solid recovered by evaporating the supernatant as a percentage of the initial dry sample (Anderson *et al.*, 1969; Ding *et al*., 2005).

The textural characteristics of extrudates were measured using a Stable Micro System TA.XT plus texture analyzer fitted with a 3PB probe. Samples were placed across the width of the three-point bend. The 10 cm length snack was then placed on heavy duty platform and the fracture characteristics or brittleness of a product at 3 mm/s test speed was measured. A force-time curve was recorded and analyzed to calculate peak force. Peak force was chosen to represent the textural properties of the extrudate (Ding *et al*., 2005). Ten randomly collected samples of each replicate were measured and given an average.

The air cells of each extrudate were carried out by Image analysis technique following the method of Sánchez-Pardoa *et al.* (2008) with some modifications. The images of cross-sectional product structure by scanning electron microscope (Joel Co. Ltd., Tokyo, Japan) with accelerating voltage of 10 kV at 10 times magnification were centrally captured at 5*8 cm to determine air-cell area. Each image was fixed a resolution of 300 dots per inch (dpi) and stored in bmp format of 386*386 pixels. The UTHSCSA Image Tool Program for Windows Version 3.0 was used to determine air-cell areas as a percentage by brightness and contrast of images.

Analysis of sensory properties

Sensory tests were conducted by 36 untrained panellists with a 9-point hedonic scale (1-extremely dislike to 9-extremely like). Panellists were asked to evaluate their preference, including color, aroma, flavor, texture and overall acceptability. Panelists included 20 female and 16 male students, between 21-30 years of age, from Food Science Department in Faculty of Science at Burapha University, Thailand.

Statistical analysis

The physicochemical and sensory property data of the effect of feed moisture content were subjected to variance analysis for statistical significance by a completely randomized design and a completely

Table 1. Effect of Hom Nil rice flour moisture content on physicochemical properties of the extrudates

Feed moisture content (%)	Expansion ratio	WAI (g water/g sample)	WSI (%)	Density (g/cm^3)	Hardness (g force)	Air cell area (%)
13	3.17 ± 0.17^b	7.32 ± 0.26^{ab}	9.01 ± 1.56^a	0.19 ± 0.03^b	328 ± 0.01^a	31.76 ± 0.24^b
15	3.60 ± 0.12^a	7.57 ± 0.24^a	5.59 ± 0.70^b	0.15 ± 0.01^c	271 ± 0.04^c	39.01 ± 0.49^a
17	2.97 ± 0.13^c	7.05 ± 0.21^b	5.03 ± 0.15^b	0.27 ± 0.02^a	297 ± 0.16^b	28.01 ± 1.55^c

$^{a, b, c}$ Sample means with the different superscript letter in common among columns are significantly different (p<0.05).

Table 2. Effect of Hom Nil rice flour moisture content on sensory properties of the extrudates

Feed moisture content (%)	Color	Aroma	Flavor	Texture	Overall acceptability
13	7.17 ± 0.83^a	6.70 ± 0.84^a	6.53 ± 0.63^a	6.07 ± 0.85^b	6.90 ± 0.88^b
15	7.23 ± 0.82^a	6.80 ± 0.92^a	6.57 ± 0.86^a	7.10 ± 1.06^a	7.60 ± 0.87^a
17	6.07 ± 0.91^b	6.17 ± 0.91^b	5.97 ± 1.00^b	3.77 ± 1.43^c	4.93 ± 0.98^c

$^{a, b,c}$ Sample means with the different superscript letter in common among columns are significantly different (p<0.05).

randomized block design, respectively. While the physicochemical and sensory property data of the effect of die-zone barrel temperature (120, 140, 160°C) and screw speed (150, 200, 250 rpm) were applied factorial (3*3) and balanced incomplete block experiment (number of sample per person=4), respectively. Determinations of all physicochemical properties were performed in triplicate. An analysis of variance (ANOVA) was checked the significance at $p \geq 0.05$ with the SPSS version 17.0 program for Windows®. Duncan's multiple range test (DMRT) was used to compare means of all treatments.

Results and Discussion

Testing performance of the laboratory extruder

Proximate composition of Hom Nil rice flour was 11% moisture, 9% protein, 3.7% fat, 3.3% ash and 73% carbohydrate. The testing performance indicated that extruded puffed Hom Nil rice snacks were produced at about 2.50 ± 0.03 kg/h on dry weight basis. Barrel wall temperature in die zone was slightly higher than setting temperature (160.83±3.58°C) due to accumulated heat. While, Barrel wall temperature in the transition section was nearly constant (80.84±1.24°C) when screw speed was set at the maximum of 300 rpm and run for 20 min.

The effect of feed moisture content on physicochemical and sensory properties of extrudates

All of the physicochemical and sensory properties of extrudates were improved by an increase of feed moisture content from 13 to 15%. For examples, expansion ratio and air-cell area of extrudates were increased about 14 and 7 %, respectively. Moreover density and hardness of extrudates were decreased 21 and 17%, respectively. The extrudate was produced from 15% feed moisture content, which indicated the highest acceptability in terms of color, aroma, flavor, texture, and overall acceptability (p<0.05, Table 1 and 2). However, at a feed-moisture content of 17% indicated the inverse affect. This might be due to the excess moisture content of feed material caused a reduction in friction. Consequently, there was an adverse effect on starch gelatinization, which resulted in a reduction of the expanded-product (Liu *et al*., 2000). Therefore the 15% moisture content of Hom Nil rice flour was selected for the next experiment.

The effect of die-zone temperature and screw speed on physicochemical and sensory properties of extrudates

Expansion ratios, WAI, density and hardness of Hom Nil rice snacks were influenced significantly by die-zone barrel temperature and screw speed (P<0.05, Table 3). An increase in screw speed led to a significant (P<0.05) decrease in snack density. For examples, an increase in screw speed was from 150 rpm to 250 rpm, at 120°C, resulted in a 52% decrease in snack density. Product density was inversely related to the expansion ratio, in accordance with the results of Suksomboon *et al.* (2011). For example, the expansion ratio of snacks increased from 2.45 to 3.17, while the density decreased from 0.46 to 0.22 g/cm3 when the die-zone barrel temperature was

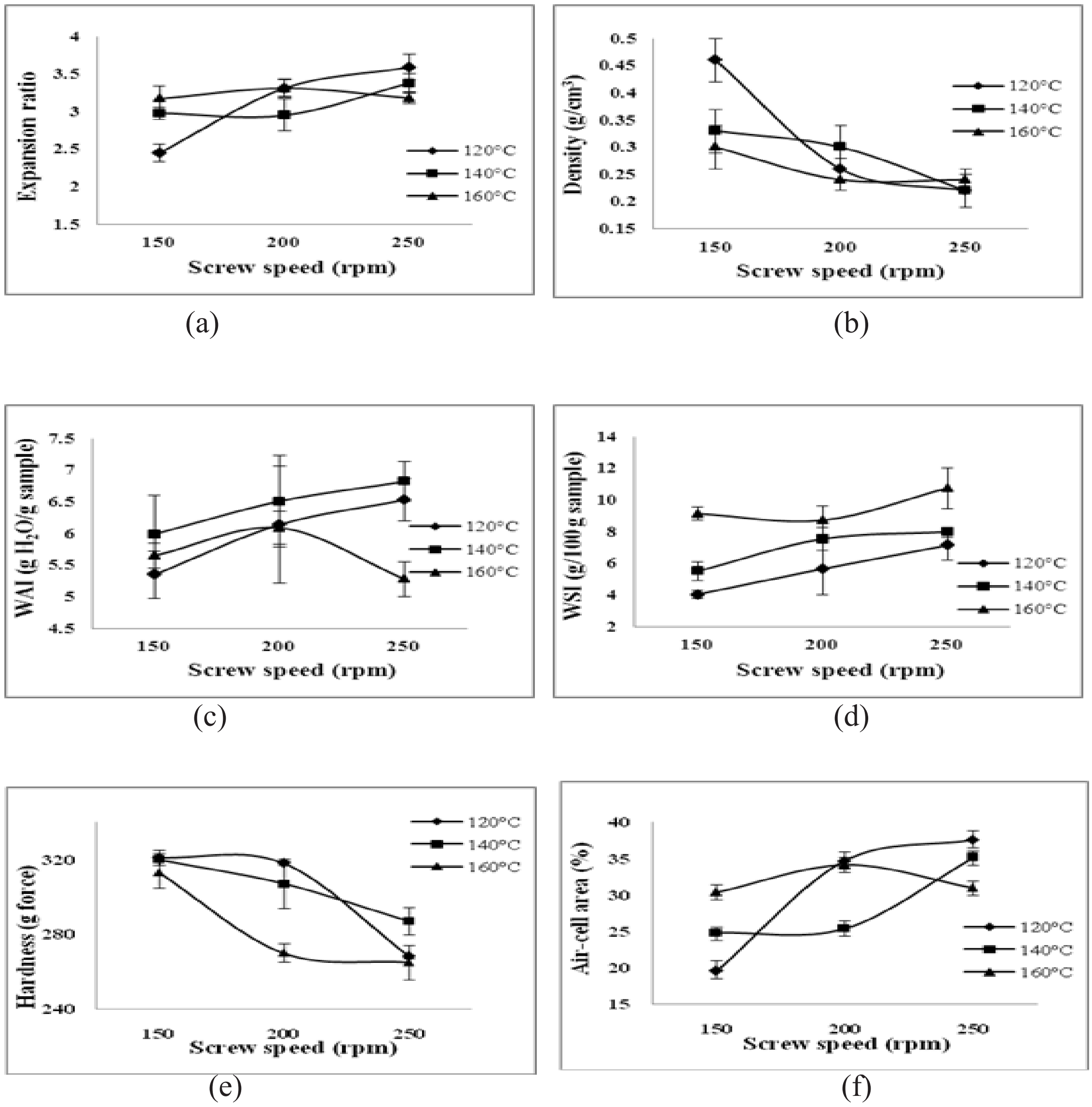

Figure 1. Effects of die zone temperature and screw speed on physiochemical properties of the extrudates

increased from 120 to 160°C at a screw speed of 150 rpm (Figures 1a and 1b). This was also in agreement with the study of expanded rice-based snack by Ding *et al.* (2005).

Screw speed was observed to have little effect on WAI. Thus, WAI values ranged from 5.35-5.99, 6.09-6.51, and 5.28-6.82 g water/g dried sample, at screw speeds of 150 rpm, 200 rpm and 250 rpm, respectively. WSI of snack increased by 11% when die-zone barrel temperature increased from 120 to 140°C at a screw speed of 150 rpm (Figure 1c). However, WAI of the extrudate declined about 23% when die-zone barrel temperature changed from 140 to 160°C at a screw speed of 250 rpm. Sacchetti *et al*. (2004) and Suksomboon *et al*. (2011) indicated that WAI of snack increased with temperature to a maximum, after which it decreased. This might be due to starch granules were partially burnt at a high temperature. Therefore, the water absorption of an extrudate could be decreased.

WSI value increased directly with barrel temperature (Figure 1d). For example, increasing die-zone barrel temperatures from 120 °C to 160°C caused a 2.3 times increase in WSI of snack at a screw speed of 150 rpm. This observation was similar to the finding of expanded rice-based snack by Ding *et al*. (2005). An increase in the die-zone barrel temperature resulted in increased product temperature and the degradation of starch increased WSI (Lei *et al*., 2005). Because WSI also depends on the quantity of soluble materials, soluble starch increased with increasing extrusion temperature due to an increase in starch degradation or the extent of gelatinization (Guha *et al*., 1997).

An increasing barrel temperature at die and screw speed resulted in a decreased hardness of the extrudate. For instance, increasing barrel temperature from 120 to 160°C was observed to cause a 15%

Table 3. F and p values of extruded- snack properties

SOV	F (p)					
	Expansion ratio	WAI	WSI	Density	Hardness	Air cell area
Temp.	5.875*(0.004)	27.583*(0.000)	47.476*(0.000)	20.939*(0.000)	36.250*(0.000)	18.772*(0.000)
Screw speed	105.466*(0.00)	19.700*(0.000)	14.476*(0.000)	151.815*(0.000)	15.755*(0.002)	155.202*(0.000)
Temp. * Screw speed	55.118*(0.000)	11.849*(0.000)	1.905^{ns}(0.153)	28.631*(0.000)	50.542*(0.000)	63.033*(0.000)

* means are significantly difference at $p<0.05$, ns means non significantly difference at $p \geq 0.05$

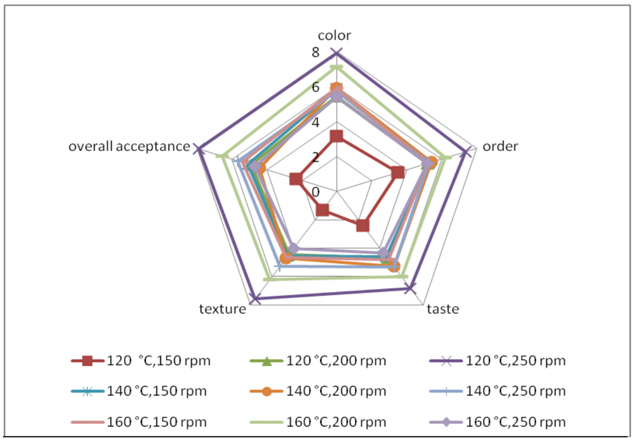

Figure 2. Effect of die-zone temperature of barrel and screw speed on sensory properties of the extudates

decrease in snack hardness at a screw speed of 200 rpm. An increase barrel temperature also decreased melt viscosity, which produced low density products with small and thin cell walls, decreasing the hardness of extrudate (Ding *et al.*, 2005). Hardness of extrudates were decreased inversely with screw speed in the range of 321-268, 320-287 and 313-265 g (force) at 120°C, 140°C and 160°C, respectively (Figure 1e). This supports the earlier conclusion by Liu *et al.* (2000) that a higher screw speed might decrease the hardness of the extrudate by increasing the temperature, leading to a higher expansion and a lower density. While, air-cell area of the extrudate was increased directly with screw speed and die barrel temperature ($p < 0.05$). An increase screw speed from 150 to 250 rpm resulted in an 18% increase in air cell area value at 120°C of die barrel temperature and a 10% increase air cell area value at 140°C with screw speed of 150 rpm and 250 rpm (Figure 1f). This result indicated the same trend of product expansion. As a result, the higher die-zone barrel temperature and screw speed were applied to gelatinize Hom Nil rice flour. The gelatinized flour was then extruded through a 3 mm diameter of die. As a result, water of the extruded product was immediately evaporated and resulted in the expansion of snacks. An increase in screw speed from 150 to 250 rpm caused higher porosity and a higher rate of expansion.

Panelists were asked to evaluate sensory acceptance in terms of color, aroma, flavor, texture and overall acceptance of snack samples. As a result, hedonic scores of the panelists on sensory evaluation for each characteristic were significant different (P<0.05, Figure 2).Color, aroma and flavor of the snack samples extruded from a 120°C barrel temperature with a screw speed of 150 rpm had the lowest scores, in the range of 1.33 to 3.50 (mostly dislike to slightly dislike). The panelists preferred the snack with the lowest density and hardness to those prepared from 15% moisture content of Hom Nil rice flour at 120°C die-zone barrel temperature and screw speed of 250 rpm which showed the highest score of texture and acceptability, about 7.6 and 8 respectively, meant like very much.

Conclusions

The laboratory single screw extruder could consistently maintain temperature during extrusion process, and only require small sample size to perform the experiment. Hom Nil rice snacks were produced at about 2.50 kg/h on dry weight basis. Feed moisture content, barrel temperature and screw speed were the important factors that affected the physicochemical and sensory properties of the extruded snack made from Hom Nil rice. The suitable moisture content for Hom Nil rice flour was 15% and the optimum conditions for the extrusion process to produce the maximum qualities of Hom Nil rice snacks, in terms of the physicochemical and sensory properties, were a feed rate of 20 g/min, die and transition zone barrel temperature of 120 and 80°C and screw speed of 250 rpm.

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