Physical characteristics of extrudate from mixed corn grit-soybean flour with treatments of moisture content and extruder barrel temperature

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Abstract. Corn is a commonly used raw material for snack production. However, corn has a relatively low protein content, approximately 7%. Consequently, adding soybean flour is expected to enhance the protein content in snacks. This study investigates the impact of moisture content and barrel temperature treatments on the physical properties of the produced extrudates. Snacks were manufactured using a SYSLG-IV twin-screw extruder with a capacity of 10-15 kg/h and a die diameter of 6 mm. The raw material utilized in the experiment comprised a mixture of 20% soybean flour and 80% corn grit. The study involved two main treatments: barrel temperature (at 120°C, 130°C, and 140°C) and moisture content (at 14%, 16%, and 18%). Parameters assessing the physical properties of the extrudates included expansion ratio, hardness, moisture content, water absorption index, and water solubility index. The results demonstrated that increased moisture content led to increased extrudate moisture content (ranging from 1.80% to 4.71%) and hardness (ranging from 17.45 N to 40.16 N). Conversely, it caused a decrease in the expansion ratio (ranging from 2.11 to 2.03), water solubility index (ranging from 8.82% to 7.01%), and water absorption index (ranging from 5.70 to 4.92).

1 Introduction

Indonesia is one of the top two countries within the Asia Pacific region with the biggest snacking habit. Globally, the revenue in the snack food segment amounts to USD 7.22 billion in 2022 and is expected to grow annually by 11.03% (CAGR 2022-2027)[1]. Indonesia's snacking habits have been seen consistently exhibiting that the snack market has the potential to expand in Indonesia. Extruded snacks were among the most commercially successful extruded foods. In recent years, extrusion technology has become a popular processing method due to its advantages, such as high versatility, high productivity, and low nutritional loss due to a high-temperature short-time (HTST) processing method [2]. Generally, extruded products are produced from high-starch raw materials such as corn, rice, wheat, potato, sorghum, cassava, oats, and barley [3,4].

Corn grit is one of the commonly used materials to produce extrudate snacks. However, corn has been reported for its limited nutrient profile with poor protein and dietary fiber contents [4]. Therefore, there is a need to enhance snacks' nutritional value. Soybeans can be added to enhance nutrients in corn-based extrudate snacks. Soybeans are known to contain more protein compared to other types of legumes [5]. In addition, Indonesia has a high interest in soybeans and their processed products, reaching 7 million tons per year [6].

Some studies have been reported on the incorporation of starch/flour and soybean into extruded products as a source of protein [7–11]. Extrusion is a high-temperature short time (HTST), in which raw materials are melted and cooked inside the barrel extruder by a combination of moisture content, pressure, temperature, and shear rate, resulting in starch gelatinization, protein denaturation, molecular transformation, chemical reaction, and vitamins degradation [12], [13] can drastically influence the final product quality. Extrusion process conditions such as barrel temperature, feed moisture content, and screw speed are critical for extruded snacks' quality characteristics [14]. Based on previous literature, it was reported that barrel temperature and moisture content significantly affected the quality of extrudates [8–15].

The expansion ratio is one of the most desirable physical properties for extruded snacks because it determines their quality [16]. However, there was limited information about corn grit and soybean flour in producing extruded snacks. Therefore, this study's primary objectives were to investigate the impact of moisture content and barrel temperature treatments on the physical properties such as expansion ratio, extrudate moisture content, hardness, particle density,

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bulk density, water solubility index, and water absorption index.

2 Materials and methods

2.1 Materials

Corn grits (*Zea mays*) were obtained from CV. Surya Grain Indonesia. Soybeans (*Glycine max* L.) were purchased from CV. Hasil Indah and ground with a disk mill. Corn grits and soybean flour were then sieved to pass through 24- and 80-sieve, respectively. A total of 21.6 kg of corn grit and 5.4 kg of soybean flour were used throughout this study.

2.2 Equipment

The primary equipment used in this study was a twin-screw extruder SYSLG-IV (Shandong Saibainuo Machinery, Co., Ltd., China) equipped with a circular die with a 6 mm diameter. Disk mill (Shandong Jimo FFC-15, China), digital scale (Ohaus PA4102, USA), and mixer (Ossel B7, Indonesia) were used to prepare the feed material. Forced air oven (Sanyo MOV-112, Japan), analytical balance (Shimadzu AUW220, Japan), vernier caliper, blender (Panasonic MXT1GN, Japan) vortex mixer (DLAB-MXS, USA), centrifuge (Kokusan H-27F, Japan), texture analyzer (Brookfield CT-3, USA) and 1000 mL-graduated cylinder were used to measure physical properties of extrudates.

2.3 Feed preparation extrusion process

Soybean flour and corn grit were mixed using a mixer (Ossel B7, Indonesia) at a 20% soybean flour and 80% corn grit ratio. The mixture's total moisture contents were adjusted to the desired values before extrusion. The mixture was stored at room temperature in polypropylene bags for 24 hours to achieve equilibrium.

2.4 Extrusion processing

Prior to an extrusion process, extruder screw speed, feeder speed, and cutter speed were adjusted at 20 rpm, 15 rpm, and 6 rpm, respectively, throughout this study. Barrel temperatures were set at 40˚C, 50˚C, 100˚C, and 120/130/140 ˚C. The raw materials were then fed into the extruder. After steady-state conditions were reached (no visible fluctuations in the electric current of the controller and stable extrudate output), extrudates were collected and dried in a forced-air oven at 105˚C for 3 hours. The dried samples were stored in a polypropylene standing pouch with silica gel and oxygen absorber until further analysis.

2.5 Experimental design

Experiments were designed using the 3x3 complete randomized design (CRD). The independent variables were moisture content (14, 16, and 18%) and barrel temperature (120, 130, and 140˚C). The dependent variables observed in the study were expansion ratio, extrudate moisture content, hardness, bulk density, particle density, water absorption index (WAI), and water solubility index (WSI). Each treatment was done in triplicate.

Table 1. Experimental design for the extrusion process

Moisture content (MC)	Barrel temperature (T)		
	120˚C	130˚	140˚
14%	T120MC14	T130MC14	T140MC14
16%	T120MC16	T130MC16	T140MC16
18%	T120MC18	T130MC18	T140MC18

Whereas T: barrel temperature (˚C); MC: moisture content (%)

2.6 Product characteristic

2.6.1 Expansion ratio (ER)

The expansion ratio was determined by dividing the extrudate diameter (measured with a vernier caliper) by the diameter of the extruder die [14]. A total of 10 samples of extruded snacks were taken randomly. The expansion ratio was calculated using Equation 1.

$$ER = \frac{\text{extrudate diameter}}{\text{die diameter}} \quad (1)$$

2.6.2 Extrudate moisture content (EMC)

Extrudate was dried in a forced air oven at 105˚C for 24 hours until a constant weight was obtained [17]. Samples were then weighed using an analytical balance, and extrudate moisture content was calculated using Equation 2.

$$EMC\ (\%) = \frac{\text{mass of water}}{\text{mass of moist sample}} \quad (2)$$

2.6.3 Particle density (PD) and bulk density (BD)

Particle density was determined as described by [18]. The mass of extrudates was weighed using an analytical scale, and extrudate dimension was measured using a vernier caliper. The particle density of extrudates was then calculated following Equation 3, assuming a cylindrical extrudate shape. Ten randomly collected extrudates were measured

$$PD = \frac{4 \text{ x mass}}{\pi \text{ x } d^2 x\ L} \quad (3)$$

Extrudates were poured into a 1000 mL measuring cylinder and weighted using a digital scale to measure bulk density. The cylinder was gently tapped on a flat surface until a constant volume was obtained [19]. The bulk density was then calculated using Equation 4.

$$BD = \frac{\text{mass of the sample}}{\text{volume of the sample}} \quad (4)$$

2.6.4 Hardness

The maximum force obtained has been taken as a measure of the hardness of the products. Low hardness value has been regarded as a desirable property for extruded snacks [20]. A texture analyzer (Brookfield CT-3, USA) equipped with a 10 kg load cell was used to test the hardness of the extruded snack. TA-39 stainless probe with a cylinder diameter of 2 mm and 20 mm length was used. Analysis was performed with the following settings: pretest speed 2mm/s; test speed 2 mm/s; return speed 1mm/s; and target distance 7 mm. Nine randomly collected extrudates were measured and reported as average.

$$\text{Hardness} = \frac{load\ (g)}{1000} \times 9.81\ \frac{m}{s^2} \quad (5)$$

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

The water absorption index indicates the amount of water immobilized by the extrudate. In contrast, water solubility indicates the amount of small molecules of soluble polysaccharide released from the starch component after extrusion. The WAI dan WSI was measured as described by [2] with minor modifications. The WAI and WSI were calculated using Equations 5 and 6, respectively. The determination of WAI and WSI was done in triplicate.

$$\text{WAI} = \frac{\text{weight of wet sediment}}{\text{weight of dry sample}} \quad (6)$$

$$\text{WSI} = \frac{\text{weight of dry solids in supernatant}}{\text{dry weight of extrudate}} \text{ x } 100\% \quad (7)$$

2.7 Statistical analysis

All experiment data were analyzed using IBM SPSS 27 software. The experimental data were analyzed using analysis of variance (ANOVA) with significance defined at p<0,05. The analysis of variance was carried out to identify the effect of operating conditions (moisture content and barrel temperature) on the final product quality.

3 Result and discussion

Table 2. Significance of the main effects and their interactions for the physical characteristics of extrudate from corn grit – soybean flour mixture

Extrusion variable	Barrel temperature	Moisture content	Interaction of both
ER	N	S	S
EMC	NS	S	S
PD	S	S	S
BD	S	S	S
H	S	NS	NS
WAI	S	S	S
WSI	S	NS	NS

- S: significant at p<0,05; NS: Not significant
- ER: expansion ratio; EMC: extrudate moisture content; PD: particle density; BD: bulk density; H: hardness; WAI: water absorption index; WSI: water

3.1 Expansion ratio

Expansion ratio (ER) was described as a degree of puffing by the sample as it exits the extruder die [7]. Moisture content, barrel temperature, and their interaction had a significant effect at p<0.05 (Table 2). ER of extrudates ranged from 1.81–2.28, with the highest value obtained at 14% moisture content and 140˚C barrel temperature treatment, while the lowest value at 18% moisture content and 120 ˚C barrel temperature treatment (Figure 1). ER of extrudate decreased as moisture content increased. Water acts as a plasticizer in the dough melts. Reducing the viscosity of the dough melts in the extruder would cause a decrease in the cooking degree of raw materials and lower the ER [21].

Another study reported that the expansion ratio decreased with increasing moisture content from 15.5% (2.58) to 18.5% (2.08). High moisture content reduced the friction between the materials and the barrel wall when shearing. On the other hand, ER of extrudates increased as barrel temperature increased from 75˚C (1.63) to 125˚C (2.08) [22]. Higher barrel temperature was attributed to a higher degree of gelatinization, increasing the ER. Moreover, in high barrel temperatures, moisture in the dough became superheated, increasing bubble formation and producing a porous structure [22,23]

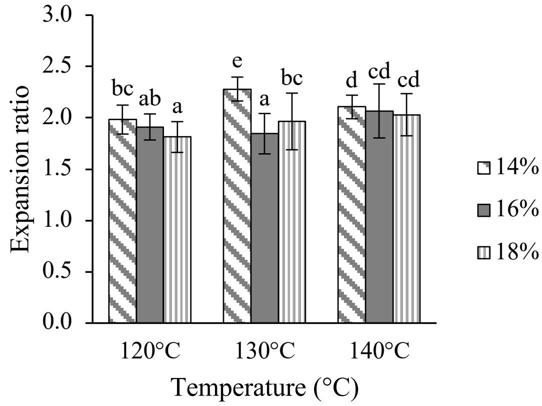

Fig. 1. Expansion ratio of extrudate under moisture content and barrel temperature treatment

3.2 Extrudate moisture content

Moisture content is a crucial parameter to determine the extrudate's final quality. As shown in Table 2, it was found that only feed moisture content and interaction between moisture content and barrel temperature had a significant effect on extrudate moisture content (p<0.05). The moisture content of corn grit-soybean flour extrudate is in the range of 1.80–4.65%, as can be seen in Figure 2. Feed moisture content had a positive correlation with extrudate moisture content. A previous study obtained a similar result and reported that extrudate moisture content increased when the moisture content of the feed was increased [24]. The extrudate moisture content increased with increasing moisture content from 18% (6.15) to 22% (6.19). Water acts as a lubricant in the extruder, lowering the shear force, pressure, and temperature generated inside the extruder, thus decreasing the amount of water vaporization. A significant difference was not observed in barrel temperature on the moisture content of the extrudate.

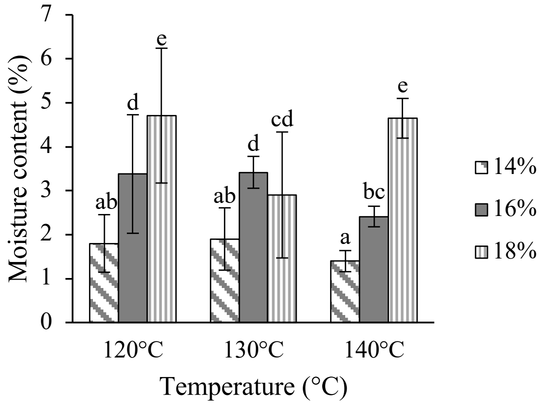

Fig. 2. Extrudate moisture content under moisture content and barrel temperature treatment

3.3 Particle density and bulk density

Particle density (PD) and bulk density (BD) of extrudates were significantly affected by moisture content, barrel temperature, and their interaction ($p<0.05$). Moisture content had a positive correlation with PD and BD. PD of extrudates ranged from 0.28 – 0.56 g/cm3, and BD of extrudates ranged from 0.16–0.41 g/cm3—increasing moisture content results in a higher density and more compact extrudate. A similar study reported that BD extrudate increased with increasing moisture content from 13% (0.114) to 17% (0.156). However, barrel temperature had a converse relationship with PD and BD. High barrel temperature promotes the formation of air bubbles along with the decrease of melt viscosity [25]. Another study also reported the negative correlation between barrel BD extrudate with barrel temperature in the range of 160˚C (0,147) to 200˚C (0.128) on defatted soybean meal, germinated brown rice meal, mango peel fiber, and corn grit-based extrudate [15]

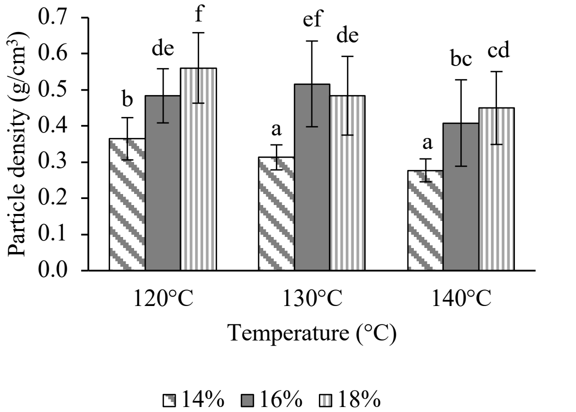

Fig. 3. Particle density of extrudates under moisture content and barrel temperature treatment

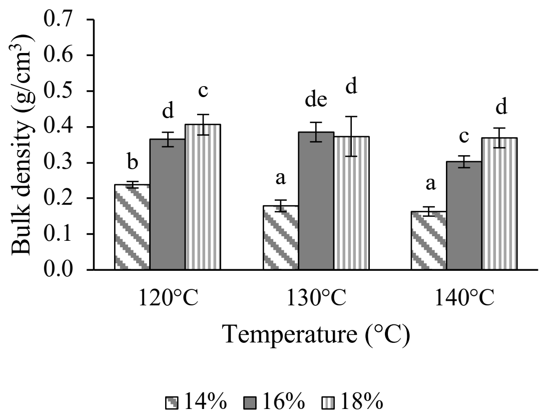

Fig. 4. Bulk density of extrudates under moisture content and barrel temperature treatment

3.4 Hardness

Hardness has a significant influence on consumer acceptability of extruded snacks. Consumer highly prefers extrudate with minimum hardness. The hardness of extrudate was significantly affected by moisture content ($p<0.05$). However, barrel temperature did not significantly affect extrudate hardness ($p<0.05$) (Table 2). The extrudate's hardness ranged from 17.45–53.00 N, with the lowest hardness obtained at 14% moisture content and 140˚C barrel temperature treatment. Increased moisture content significantly increases extrudate hardness ($p<0.05$). Increased moisture content could lower the cooking degree of starch in the material and reduce water vapor pressure in the extruder [25]. This decrease in pressure could then lead to reduced bubble growth in the material, resulting in harder extrudate [26]. A similar trend has been reported that hardness increased with increasing moisture content from 20% (20.39N) to 28% (33.13N) for corn, finger millet, elephant foot yam, and defatted soybean flour-based extrudate [27].

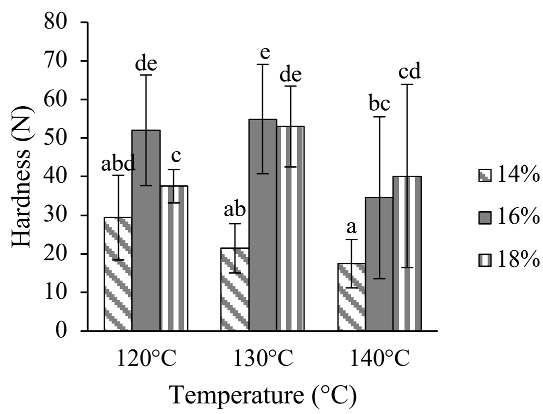

Fig. 5. Extrudate hardness under moisture content and barrel temperature treatment

3.5 Water absorption index and water solubility index

The water absorption index (WAI) reflects the ability of starch to absorb water and is used as an indicator of the degree of gelatinization. Both variables and their interaction affected the WAI of extrudates significantly ($p<0.05$) (Table 2). WAI of extrudates varied from a minimum value of 4.92 to a maximum value of 7.01 (Figure 6). Another study [7] reported that WAI values of extrudates ranged from 6.62 to 5.46. It was found that WAI tends to increase at a higher temperature. This increase was probably caused by the more significant damage polymer chain and hydrophilic bonds at higher temperatures, causing a reduction in the binding ability of molecules [27].

However, increased moisture content led to a reduction in WAI values. Water can act as a lubricant inside the extruder, reducing the shear degradation of starch and reducing the WAI of extrudates [27]. Meanwhile, WSI is used as an indicator of molecular component degradation. The WSI value of extrudates was only significantly affected by barrel temperature. WSI of extrudates varied from 7.01–10.18% (Figure 7). Higher barrel temperature caused starch molecules to degrade into smaller molecular weight fractions and increase solubility, increasing WSI [25]. Even though moisture content did not significantly affect the WSI of extrudates, WSI values tended to decrease as moisture content increased.

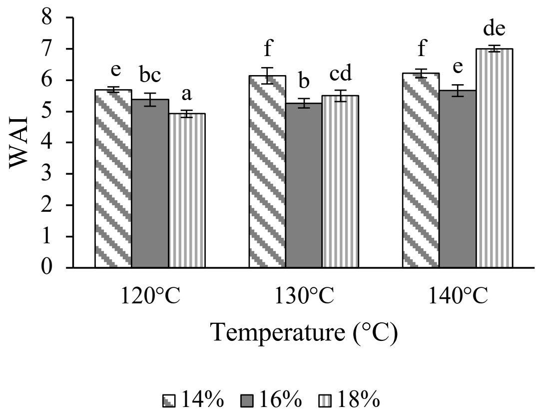

Fig. 6. Water absorption index of extrudate under moisture content and barrel temperature treatment

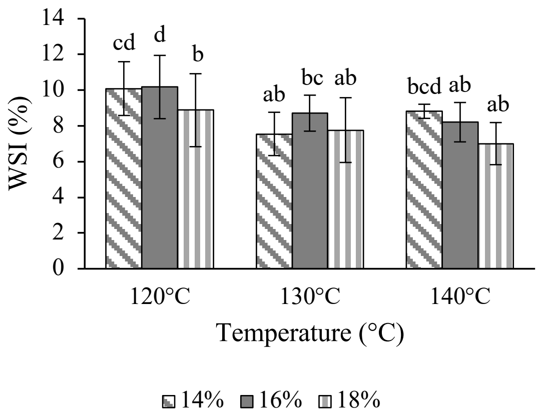

Fig. 7. Water solubility index of extrudate under moisture content and barrel temperature treatment

4 Conclusion

The result showed that moisture content and barrel temperature affected extrudate characteristics. An increase in the feed moisture content affects the expansion ratio negatively. It positively affects the extrudate moisture content, particle density, bulk density, and water absorption index. At the same time, barrel temperature positively affected the expansion ratio and water solubility index and negatively affected the particle density, bulk density, water absorption index, and hardness.

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