Proceedings of the 11th International Conference on Agriculture, Vol. 9, Issue 1, 2024, pp. 69-82

ISSN 2682-7018 online
DOI: https://doi.org/10.17501/26827018.2024.9106

EFFECT OF SORGHUM FLOUR-CORN GRITS RATIO AND MOISTURE CONTENT ON PHYSICAL PROPERTIES OF EXTRUDATES USING TWIN-SCREW EXTRUDER

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Abstract: Sorghum has been widely developed in the last decade, but the current utilization of sorghum is still limited. For this reason, innovation in food products that can utilize this material is needed. The extrusion process can turn certain food products into snacks with minimal processing. In addition, this snack can directly impact for food industry because is such a product innovation for health-conscious consumers. This study also aimed to determine the effect of sorghum-corn blend ratio and initial moisture content on the physical properties of extrudates. The material used was sorghum flour mixed with corn grits. The equipment used was a lab-scale twin screw extruder (Shandong, SYSLG-IV) with a capacity of 5 - 10 kg. This research design used two treatments, namely the ratio (0%, 10%, 20%, 30%, and 40%) and the initial moisture content of the material (12%, 14%, 16%, and 18%). Furthermore, the physical properties of the extrudate were analyzed, including final moisture content, expansion ratio, particle density, density, water solubility index, water absorption index, color, and hardness. The results showed that increasing the sorghum ratio up to 40% decreased the expansion ratio and lightness and increased particle density, bulk density, hardness, WAI, WSI, and final water content. Blending sorghum with corn grits up to 20% still showed consumable physical properties of the extrudate, while the highest moisture content still allowed as food was 14%.

Keywords: physical properties, corn grits-sorghum flour, extrusion process, moisture content, twin screw extruder, snack innovation.

Introduction

Indonesia is one of the countries characterized by fertile soil, and sorghum is a prioritized food crop by the Indonesian government, in addition to rice. Sorghum's production in eastern Indonesia (East Nusa Tenggara, Indonesia) in the range of 2016-2023 has increased. This trend will support potential in food security and agribusiness. The utilization of sorghum, among others, as flour for bread mixture and animal feed (Harmini, 2021) can even be used as an alternative ingredient for rice mixture for people with diabetes mellitus because it has a large amount of phenolic and strong antioxidant activity (Dlamini and Solomon, 2016). However, public interest in sorghum consumption is still low due to limited knowledge of sorghum processing. For this reason, it is necessary to diversify food for sorghum plants to realize food security in Indonesia. Utilization of sorghum using extrudates technology to produce snacks is an alternative to overcome this diversification in sorghum plants.

Snacks or extrudates are foods favored by people of various ages (Mardiana *et al.*, 2023). Children also have a high interest (Amalia *et al.*, 2012). One method of making snacks or extrudates is the extrusion process. The extrusion process is included in the HTST (High Temperature Short Time)

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category (Abilmazhinov *et al*., 2023). Research done by Menis *et al.* (2013) showed that extrudates based on corn alone can give the effect of good texture characteristics, but when viewed in terms of nutritional levels, corn needs to be added to increase food fiber. Therefore, it is necessary to add a mixture of other ingredients to increase nutrition, one of which is the addition of sorghum. This is also supported by the fact that the level of demand for snacks is increasing but inversely proportional to consumer interest in vegetables and fruits (Kand and Grubard, 2015). Therefore, the productio n of snacks balanced with attention to nutrition in it can be one of the effective ways to meet consumer needs and can also create a new view in food technology to produce nutritious snacks. There are similar studies related to the manufacture of sorghum flour-based snacks. However, the making of corn grits-based snacks with sorghum flour has not been found. In the research of Kaur *et al.* (2023), there is food manufacturing using a ratio of sorghum flour to chickpea flour (80:20), and variations in moisture content of 14%, 16%, and 18% have been carried out. In his research, a twin-screw extruder was used. The measured variables include SME (Specific Mechanical Energy), ER (Expansion Ratio), Bulk Density, Hardness, and Color Characteristics. The results obtained showed a low ER number. This is because the mixed material used in this study has a high starch content (high protein). Therefore, to produce fluffy and crunchy extrudates, it is necessary to add a mixture of ingredients such as corn. Several things can influence the physical characteristics that occur in extrudates. One is the ingredient ratio (Jozinovic *et al*., 2017).

Unfortunately, information about extrudates from sorghum composition ratio and moisture content is limited. Research on corn grits-based snacks with sorghum flour has not been widely researched, especially those produced with an in-screw extruder. Therefore, this study aims to determine the physical properties of snacks based on corn grits and sorghum flour.

Methods

Materials and Tools

The tools used in this study are a twin-screw extruder (SYSLG IV, Cina) mixer (Ossel B7), analytical balance (Ohaus PA4102), measuring cup, vortex (DLAB MX-S), centrifuge (Kokusan H-27), oven (Sanyo MOV-112), blender (Miyako G101), texture analyzer (Brookfield CT-3), colorimeter (TES 135A, Taiwan) and calliper.

The materials used include corn grit from CV Surya Grain (Sidoarjo, East Java) with a mesh size of 24 and a moisture content of 11.13% and white sorghum flour from PT Kusuka Ubiku (Bantul, Yogyakarta) with a mesh size of 80 and a moisture content of 7.953%.

Methods

This research used a factorial randomization formation complete block design (CRD) of 5 x 4, with treatment of concentration and initial moisture content of ingredients. Variation of material ratio, namely 0%, 10%, 20%, 30%, and 40%. Variation of the initial moisture content of the ingredients used consists of 4 levels, namely 12%, 14%, 16%, and 18%. The experiment matrix is listed in the table below (Table 1).

Table 1. Matrix experiment

Initial Moisture Content	Ingredients				
	0%	10%	20%	30%	40%
12%	SF0MC12	SF10MC12	SF20MC12	SF30MC12	SF40MC12
14%	SF0MC14	SF10MC14	SF20MC14	SF30MC14	SF40MC14
16%	SF0MC16	SF10MC16	SF20MC16	SF30MC16	Sf40MC16
18%	SF0MC18	SF10MC18	SF20MC18	SF30MC18	SF40MC18

Note :

SF = Ratio sorghum flour to corn grits

MC = Moisture content

All experiment was repeated three times. The extrusion process is carried out with temperature settings T1=40°C, T2=50°C, T3=100℃, and T4=120°C. The screw speed is 1200 rpm, the feeder speed is 900 rpm, and the cutter speeds the 300 rpm used experiments using a die diameter of diameter 6 mm.

Measurement of Physical Properties

Expansion Ratio (ER)

Expansion ratio measurement can be calculated by comparing the diameter of the extrudate and the diameter of the die (Equation 1).

$$Expantion\ ratio = \frac{Extrudates\ diameter}{Die\ diameter} \quad (1)$$

Particle Density (PD) and Bulk Density (BD)

Particle density measurement is measured by weighing the extrudate's mass length and diameter (Equation 2). After that, a comparison was made between the weight and the volume of the extrudate. Bulk density is measured by comparing mass to volume (Equation 3).

$$Particle\ density = \frac{4 \times m}{\pi \times D^2 \times L} \quad (2)$$

$$Bulk\ density = \frac{Extrudates\ weight\ (g)}{Volume\ (ml)} \quad (3)$$

Moisture Content (MC)

The moisture content of the extrudate was evaluated using the thermogravimetric method following the method of Zambrano et al. (2022). The pulverized extrudate was oven (Sanyo MOV 112, Japan) at 105°C for 24 hours to a fixed mass. Then, calculated with Equation 4

$$Moisture\ content\ \ (\%\, w.b) = \frac{m_{water}}{m_{wet\, sample}} \times 100\% \tag{4}$$

Water Absorption Index (WAI) and Water Solubility Index (WSI)

WAI is when 1 gram of sample material is then centrifuged. Then, the solid material is divided by the mass of the initial material (Equation 5). While WSI, the water is measured and put into the oven (Equation 6).

$$WAI = \frac{wet\ sediment\ mass}{dry\ sediment\ mass} \tag{5}$$

$$WSI = \frac{mass\ of\ dissolved\ solids\ in\ the\ supernatant}{dry\ sample\ mass} \times 100\% \tag{6}$$

Hardness (H)

Extrudate hardness was measured using a texture analyzer (Brookfield CT-3, USA) with a probe diameter of 2 mm and a length of 20 mm. Hardness is done to determine the crispness of the extrudate (Equation 7).

$$Hardness\ N.mm^{-2} = \frac{load\ (g)}{1000}\ x\ \frac{9{,}81\,\frac{m}{s^2}}{probe\ surface\ area} \tag{7}$$

Statistical analysis

The data acquired were analyzed using two-way analysis of variance (ANOVA) to determine whether there was an effect of material ratio and moisture content of the mixture and their interaction on the physical properties of the extrudate. Duncan Multiple Range Test and ANOVA were conducted using IBM SPSS 29, while Technique for Others Preference by Similarity to Ideal Solution (TOPSIS) analysis from Microsoft Excel 2019 software.

Result and Discussion

ANOVA result

Table 2. Significance between sorghum flour ratio with moisture content on physical properties extrudates

Extrusion Variable	Physical Measurement							
	ER	PD	BD	MC	H	WAI	WSI	L
SF	*	*	*	*	*	*	*	*
MC	*	*	*	*	*	*	*	*
SF*MC	*	*	*				*	*

*Note: SF = Ratio sorghum flour to corn grits , MC = Moisture Content *) = Significantly different at $p<0.05$*

Physical Measurement Result

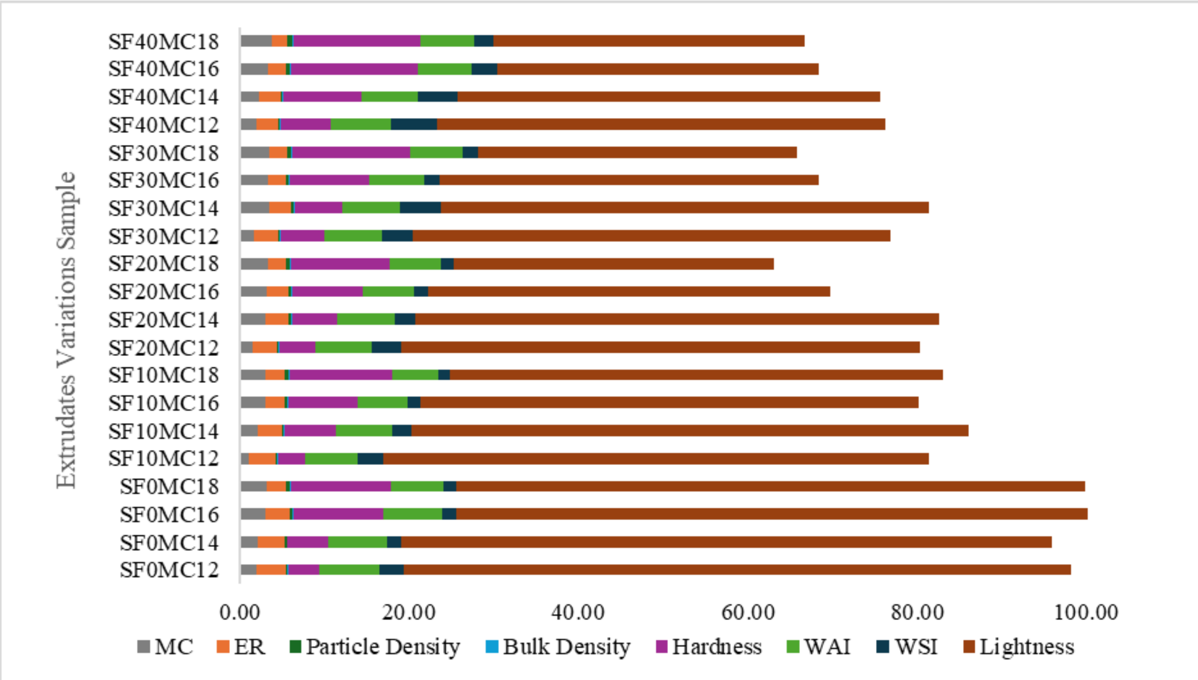


Figure 1. Extrudates physical properties result

Expansion ratio (ER)

The expansion ratio is influenced by several things, one of which is the ratio of ingredients, moisture content, or both ($p<0.05$) (Table 2). An increase in the initial moisture content of the material in the extrudate results in a small expansion ratio. This is caused by the rise in the initial moisture content of the material, which can trigger the gelatinization of the starch material (Seth *et al.*, 2015). The expansion ratio value in the extrudate also decreased as the sorghum ratio increased. This is in line with research by Dlamini and Solomon (2016) on sorghum flour-based extrudates with a ratio of 50% - 90%, showing expansion ratio values between 1.99 - 1.57. This phenomenon indicates that the higher the ratio of sorghum given, the lower the expansion ratio value produced. The low expansion ratio produced is because sorghum has a higher protein content compared to corn (Murtini *et al.*, 2021). This protein will bind starch and water. Thus, the water that hydrates the starch in the gelatinization process will be reduced, and starch expansion will be reduced. This research showed that the expansion ratio reaches 3.23 on the ratio of sorghum flour 90:10 (Figure 1). It proves that mixed corn and sorghum flour can make ER by 62.31% much bigger.

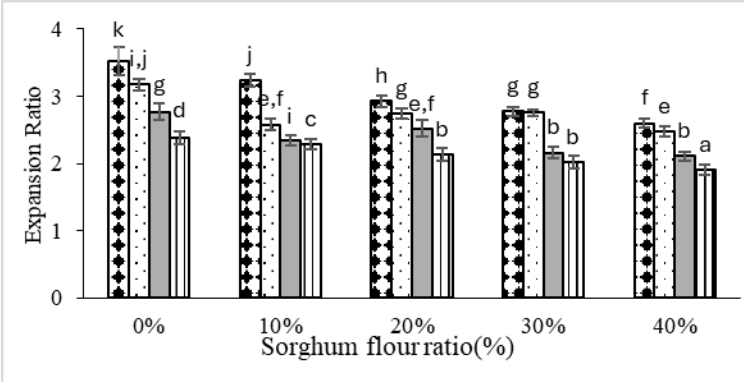


Figure 2. Extrudates expansion ratio with treatment sorghum flour ratio and moisture content.

Particle density (PD) and Bulk Density (BD)

Particle density and bulk density are influenced by several things, one of which is the ratio of ingredients, moisture content, or both ($p<0.05$) (Table 2). Particle and bulk density have an inverse ratio to the expansion ratio. The higher the value of particle and bulk density, the lower the expansion ratio (Murtini *et al.*, 2021). Particle and bulk density of the extrudate after drying ranges from 0.14 - 0.51 g cm^{-3} (PD) and 0.086 – 0.199 g cm^{-3} (BD). The higher the initial moisture content of the material, the greater the particle and bulk density of the product (Deepthi *et al.*, 2016). This happens because the greater the moisture content, the greater the mass of the extrudate produced. The ratio of ingredients also affects the particle and bulk density of the extrudate (Figures 2 and 3). This is because the higher the ratio of sorghum, the higher the protein supply in the material (Caliskan *et al.*, 2015). The high protein content will result in the formation of air bubbles in the extrudate, which will be reduced. Thus, the shape of the extrudate will be small. The shape of the extrudate will affect the volume produced (Murtini et al., 2021).

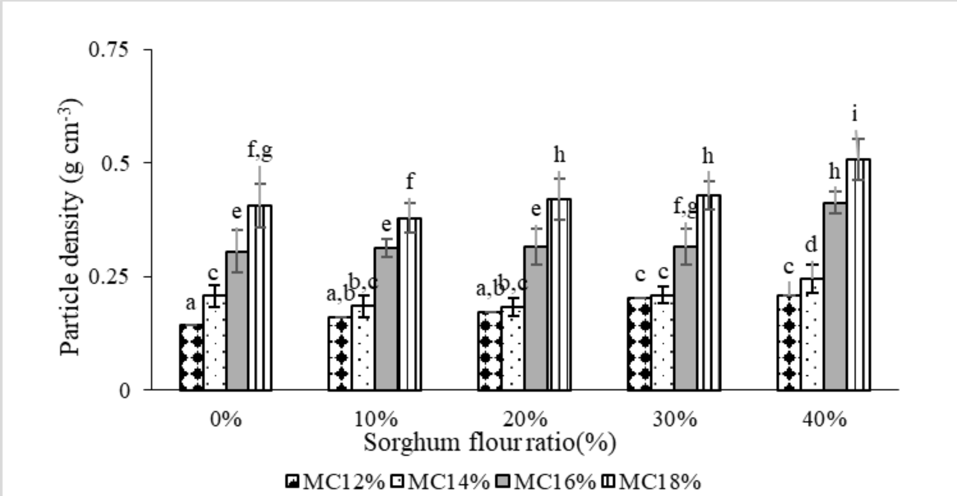


Figure 3. *Extrudates particle density with treatment sorghum flour ratio and moisture content.*

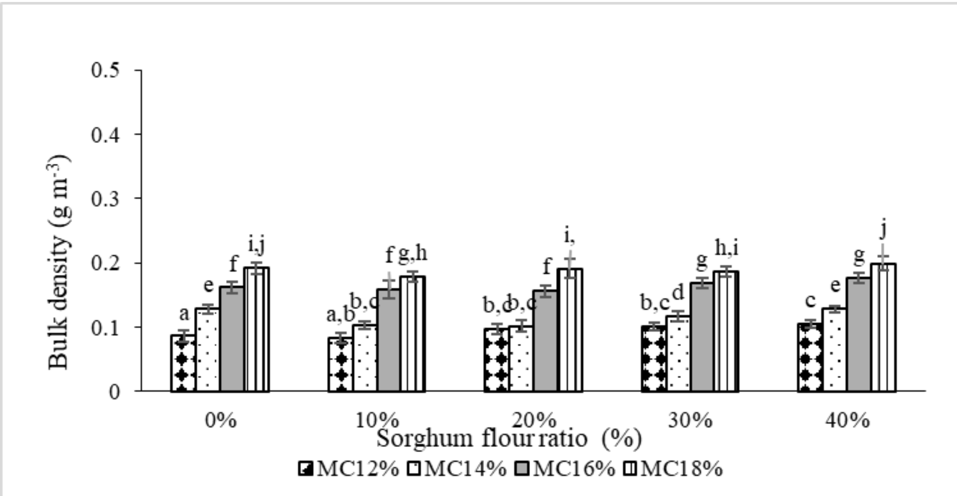


Figure 4. *Extrudates bulk density with treatment sorghum flour ratio and moisture content.*

Moisture Content (MC)

The extrudate moisture content is influenced by several things, one of which is the ratio of ingredients and moisture content ($p<0.05$) (Table 2). The moisture content of the final material is one of the physical properties that needs to be considered. This is because low moisture content affects stability during storage (Zambrano et al., 2022). The moisture content of the extrudate after drying ranges from 1.70%. The higher the moisture content of the material, the higher the moisture content of the resulting product. The results obtained are in line with research conducted by Sharifi et al. (2021) on corn grits-based extrudates with moisture content results of 4.1% - 6.37%. The moisture content value of the extrudate tends to be lower because, in this study, there is a mixture of white sorghum flour, which contains protein in it, so that it results in the level of the extrudate after drying. The EMC containing the sorghum ratio decreased compared to the corn grits extrudate (control) because of the use of barrel temperature (T=120°C), which can convert water from the liquid phase to the vapor phase. Water plays a role in hydrating the starch content in sorghum and making the starch plastic and chewy. When passing through the last barrel, a viscoelastic melt will form (Murtini et al., 2021).

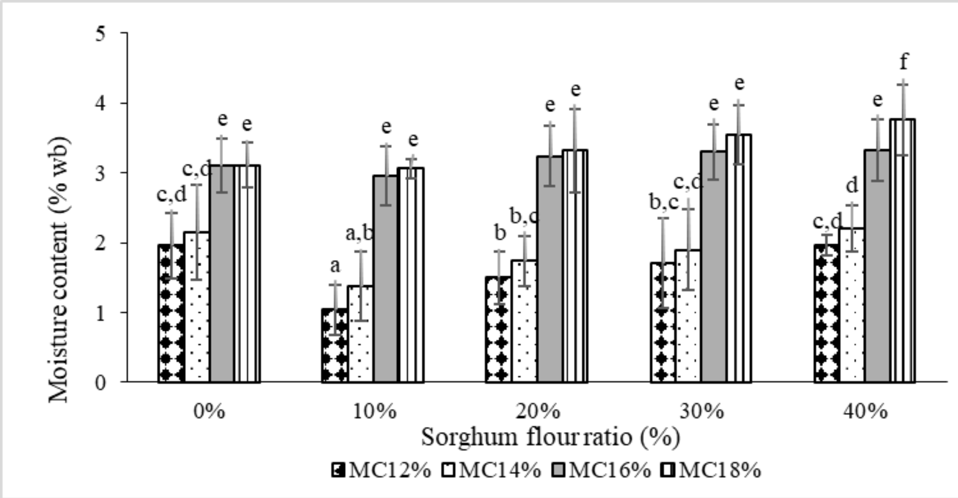


Figure 5. Extrudates moisture content with treatment sorghum flour ratio and moisture content.

Water Absorption Index (WAI) and Water Solubility Index (WSI)

The WAI is influenced by several things, one of which is the ratio of ingredients and moisture content (p<0.05) (Table 2). Water Absorption Index (WAI) is one of the most important physical properties of extrudates. This is because (WAI) can indicate the level of starch gelatinization and the level of water absorption by starch (Yağci and Göğüş, 2008). At high moisture content, starch's gelatinization rate decreases, leading to a decrease in WAI (Ding *et al.*, 2006). Besides being influenced by initial moisture content, WAI is influenced by the sorghum ratio. The higher the sorghum ratio, the higher the WAI will be. In accordance with research conducted by Dlamini and Solomon (2016), extrudates based on white sorghum flour with soy flour (50% - 90%) showed WAI values in the range of 10.8 - 15.55 (g/g) (Figure 5). The resulting WAI value is quite high because it is a mixture of soy flour that is rich in protein. Based on the research by Kaur *et al.* (2023), in chickpea flour-based extrudates, the higher the ratio of chickpea flour, the higher the amylose or amylopectin content.

Meanwhile, the WSI is influenced by several things, one of which is the ratio of ingredients, moisture content, or both (p<0.05) (Table 2). WSI values after drying showed values of 1.3 - 5.55 (Figure 6). Increased moisture content in the extrusion process can affect the reduction of protein denaturation, which results in a decrease in WSI value (Bardie and Mellowes, 1991). This is supported by the research of Hernandez *et al.* (2007), which states that WSI will increase along with the increase in moisture content and temperature. In sorghum flour (11 g), protein is higher than protein in corn grits (7 g). Palembe *et al.* (2020) stated that WSI is not just caused by starch content but can be formed by other soluble components. It is an indication of the degree of starch gelatinization. This can also be an indication of how much polysaccharide comes out of the starch during the extrusion process (Ding *et al.*, 2006).

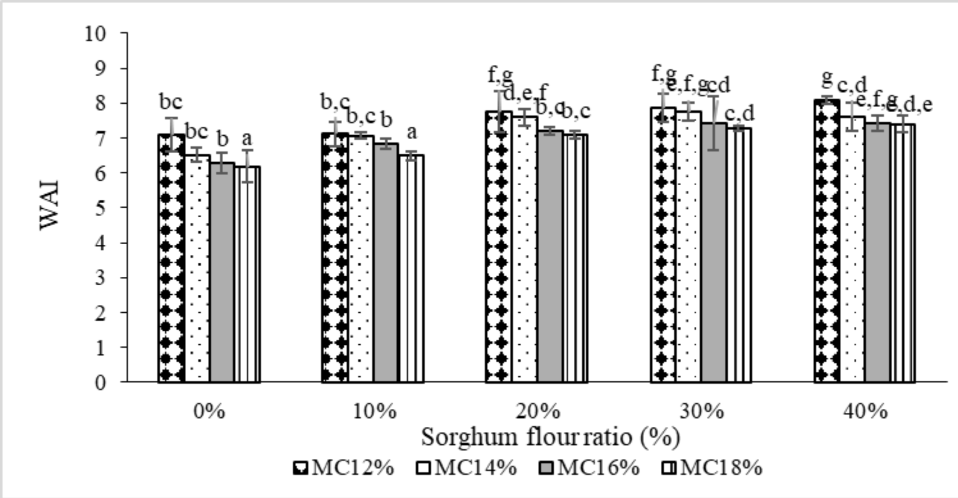


Figure 6. *Extrudates water absorption index with treatment sorghum flour ratio and moisture content.*

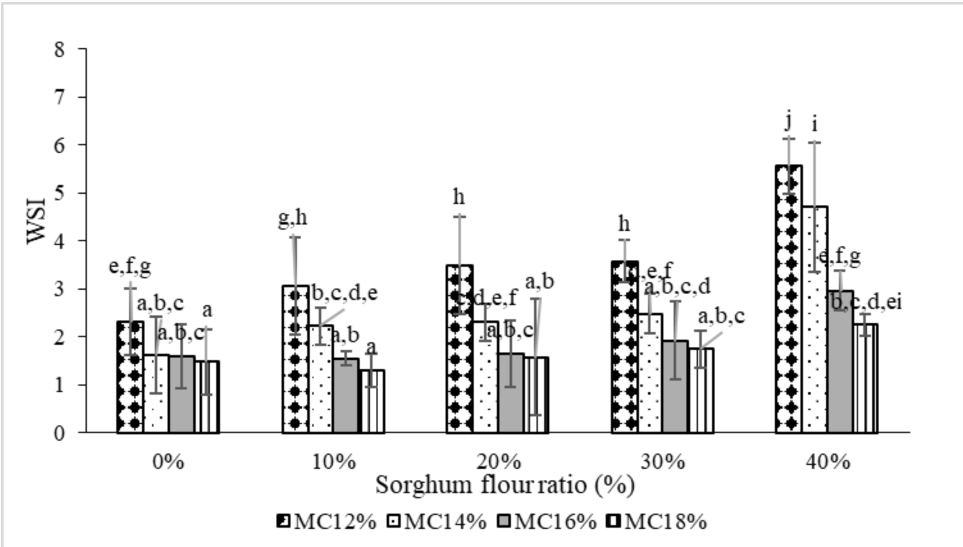


Figure 7. *Extrudates water solubility index treatment sorghum flour ratio and moisture content.*

Hardness (H)

The hardness is influenced by several things, one of which is the ratio of ingredients and moisture content ($p<0.05$) (Table 2). The lowest hardness value was achieved by the ratio of 10% sorghum with an initial material moisture content of 12% (SF10MC12), which was 3.92 N (Figure 7). The higher material moisture content will be followed by a high level of product hardness. Research by Kaur *et al.* (2023) on sorghum-based extrudates with chickpea flour (MC 14 - 18%) obtained hardness values of 98.97 N - 111.12 N. This is due to the role of water as a plasticizer in the material to reduce viscosity, cooking level, and water vapor pressure. These factors can inhibit the formation of air bubbles, thus making the extrudate dense and hard. Apart from moisture content, the sorghum ratio also affects the hardness of the extrudate. The higher the ratio of sorghum given, the higher the hardness value of the extrudate. According to research by Tadesse *et al.* (2019), soy flour-based extrudates with a ratio variation of 0% - 20% showed a hardness value of 96.48 N - 112.77 N. The hardness value differs because the material used has a higher protein content than sorghum flour.

Protein content correlates with decreased expansion due to starch-protein interactions (Pelembe *et al.*, 2002).

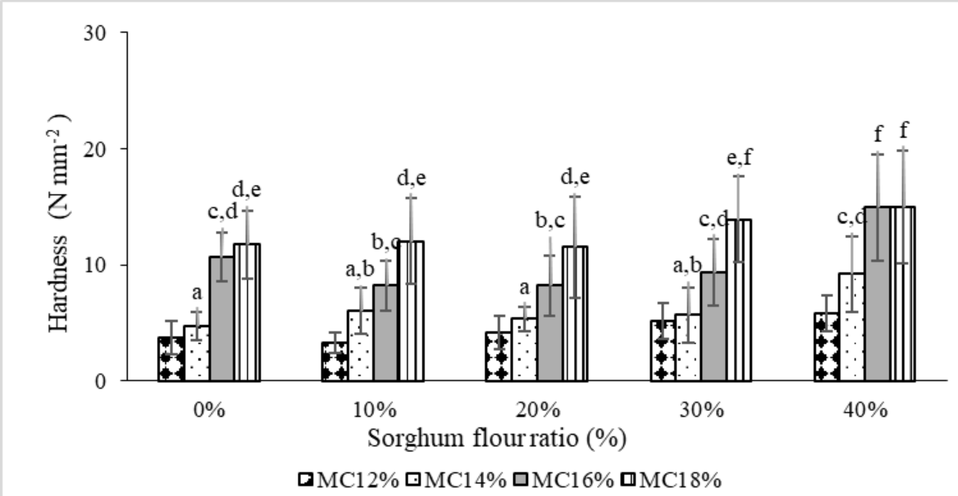


Figure 8. *Extrudates hardness treatment sorghum flour ratio and initial moisture content.*

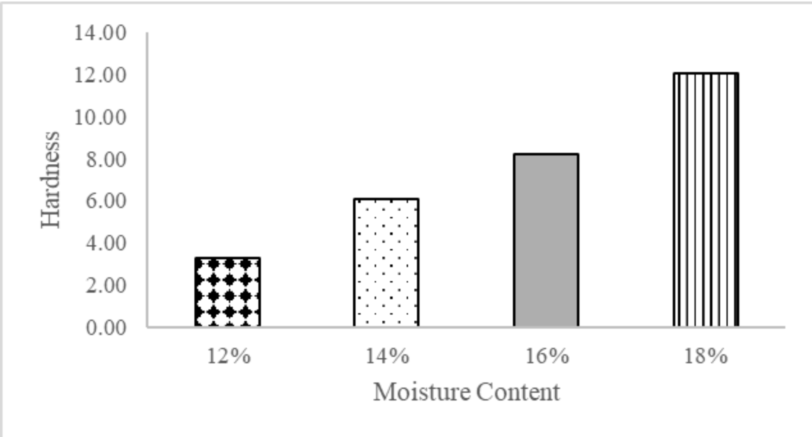


Figure 9. *Extrudates hardness treatment sorghum flour ratio 10% with 12%,14%,16% and 18% moisture content.*

Lightness

L* values were significantly affected by extrusion temperature, initial moisture content of the ingredients, and the interaction between them at $p<0.05$ (Table 2). The L* value tends to decrease as the moisture content increases. Based on a study by Kaur *et al.* (2023) on sorghum flour-based extrudates with chickpea flour with varying moisture content (14%, 16%18%), it has a lightness range of 59.71 - 68.30. The decrease in lightness can be caused by the Maillard reaction between proteins and sugars in the material (Altan and Maskan, 2012). The color from extrudates can be shown because natural pigments are found in the materials used during the extrusion process. Sorghum flour used for this research is whole crushed sorghum seeds (including the skin), which can make the extrudates darker. Therefore, as long the ratio of sorghum flour increases, L* values (lightness) will decrease. Compared with corn grits, sorghum flour has a higher protein content, so the Maillard reaction happens (Rollandeli *et al.*, 2020).

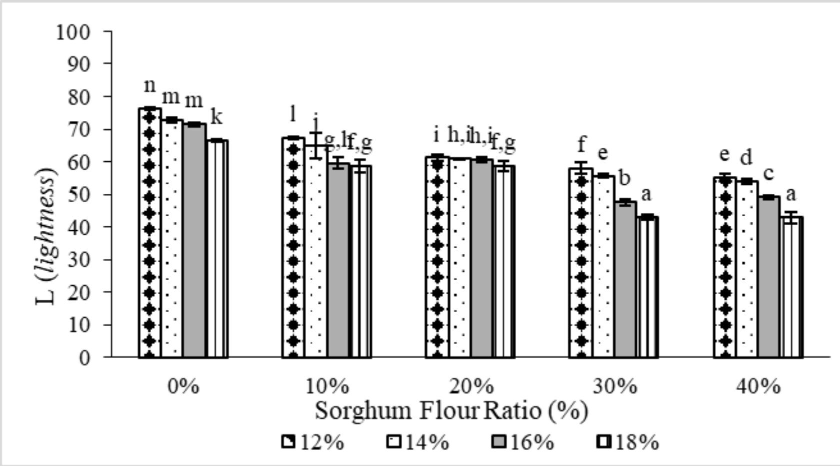


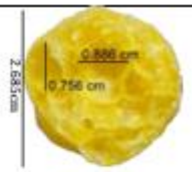
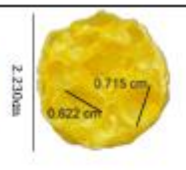
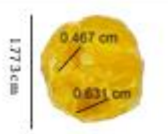
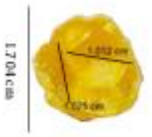
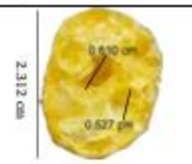
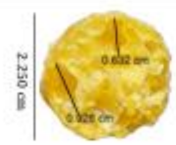
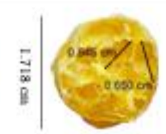
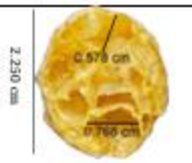
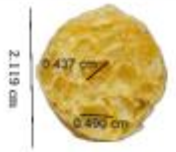
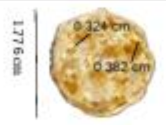
Figure 10. Extrudates lightness treatment sorghum flour ratio and moisture content.

Technique for Others Preference by Similarity to Ideal Solution (TOPSIS)

Based on the TOPSIS analysis conducted in this research, the best extrudate is obtained from the ratio of 10% sorghum flour ingredients with a variation of % initial moisture content of 12%.

Visual Extrudates

Table 3. Extrudates pore visually with the treatment of variation ratio sorghum flour and moisture content

Sorghum Flour Ratio	Initial Moisture Content			
	12%	14%	16%	18%
0%				
10%				
20%				
30%				
40%				

Proximate Analysis

Table 4. Proximate Analysis Extrudates

Extrudate	Proximate Analysis						
	Ash (%)	Fat (%)	Protein (%)	Carbo(%)	InsolubleFibber (%)	Soluble Fibber (%)	Fibber Total (%)
Control (0%)	0.766	1.268	5.688	65.557	3.361	0.247	3.608
SF (10%)	0.780	1.475	6.229	64.633	6.144	0.335	6.478
SF (20%)	0.865	1.565	7.150	63.503	6.770	0.415	7.185
SF (30%)	1.031	1.745	7.743	62.403	7.325	0.463	7.788
SF (40%)	1.118	2.110	8.287	61.900	8.427	0.552	8.979

Note: SF = Ratio sorghum flour to corn grits

Conclusion

Based on this research that we use twin screw-extruder SYSLG-IV (Shandong, China), variations in ingredient moisture content and sorghum flour ratio significantly affected all parameters of the physical properties of the extrudate. Rising the moisture content of the ingredients decreased the expansion ratio, lightness, WAI, and WSI. While increasing the ratio of sorghum flour can improve the expansion ratio, particle density, bulk density, hardness, WAI, and WSI. According to TOPSIS Analysis, the best preference for extrudates is sorghum flour ratio 10% and moisture content 12%. Many aspects can improve for the better result, such as can variate temperature barrel so we know the product (extrudates) can reach the best crispiness and can add some another grain (healthy goals).

Acknowledgment

The authors much obliged for the kindness and support of the Food and Postharvest Engineering Laboratory, Department of Agricultural and Biosystem Engineering, Faculty of Agricultural Technology, Universitas Gadjah Mada during the research until this thesis can be publised.

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