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Physical Properties of Extrudates Based on Corn Grit, Mocaf Flour and Gaplek Flour Using a Twin Screw Extruder with Treatment of Moisture Content and Barrel Temperature

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ABSTRACT

Cassava is a commodity that has not been widely innovated on. Mocaf flour and gaplek flour can be innovated as snacks using extrusion technology. This study examined the effects of varying ratios of mocaf/gaplek flour to corn grits (0% / 10% / 20%), initial moisture content (14 / 16 / 18%), and barrel temperature (120 / 130 /140°C) on the physical properties of the extrudate and to characterize the physical properties of the extrudate using PCA analysis. Physical properties such as expansion ratio, particle density, moisture content, color (L and b), water absorption index (WAI), water solubility index (WSI), and hardness were analyzed. The extrusion process was performed using a SYSLG-IV twin screw extruder (10-15 kg/hour capacity). The addition of mocaf/gaplek flour increased particle density, moisture content, L, and hardness but decreased the expansion ratio. Initial moisture content had a negative effect on the expansion ratio, WAI, and WSI while having positive effect on particle density, moisture content, and hardness. Increasing barrel temperature decreases the expansion ratio and moisture content but increases WAI and WSI. Extrudate treated with 14% moisture content was found to have better physical properties.*

1. INTRODUCTION

Cassava (*Manihot esculenta Crantz*) is a commonly grown food crop and is widely used as a staple food in Indonesia (Nasir *et al*., 2021; Purwadi *et al*., 2021). Based on FAO data in 2022, cassava production in Indonesia reached 13.57 million tons (FAOSTAT, 2022). Previously, cassava has been sold raw or processed into semi-finished materials such as flour or processed into ready-to-eat products such as tape (Philia *et al*., 2020). However, cassava has not been widely innovated as another food ingredient.

Gaplek flour and mocaf flour (modified cassava flour) are made from processed cassava that are widely sold in the market. Gaplek flour is prepared by peeling, cutting, drying, and grinding of cassava, while mocaf flour is cassava flour that has gone through a modification process in the form of fermentation (Haryadi, 2011; Putri *et al*., 2018). The modifications made during the manufacture of mocaf flour make mocaf flour have a higher protein content and better physicochemical properties than cassava flour and tapioca flour (Kardhinata *et al*., 2019). Corn (*Zea mays*) is widely used in the manufacture of extruded snacks because of its ability to produce well-expanded snacks (Fayose, 2013). In addition, corn is a widely cultivated cereal crop in Indonesia with a total production of 23.6 million tons in 2022 (FAOSTAT, 2024; Marta *et al*., 2017).

Snacking is a common habit in most countries and is increasing over time (Vatanparast *et al*., 2020). In Indonesia, the snacks market is expected to increase by 7.72% per year (CAGR 2024-2028) (Statista, 2023). This shows that the development of snack food products has great potential in Indonesia.

Extrusion technology is one of the technologies that can be used to produce snack foods. Extrusion is a popular method because it has several advantages such as high productivity, efficiency, and can produce various types of products (Choton *et al*., 2020; Pathak & Kochhar, 2018). Extrusion involves several processes at once such as mixing, heating, and forming resulting in products with varying shapes, sizes, and textures (Adekola, 2016). Extrusion technology has enabled the manufacture of cereal and tuber-based snacks, such as corn and cassava. The combination of cassava and corn allows for a better extrudate than extrudates made only from cassava (Leonel *et al*., 2009; Tumwine & Asiimwe, 2019). Therefore, the combination of corn and cassava as ingredients for extruded snacks has the potential to make snacks that are acceptable and favorable. However, there is not much information available on the manufacture of extruded snacks based on corn grits, mocaf flour, and gaplek flour.

Therefore, this study aimed to characterize the physical properties of extrudates made from a combination of corn grits-gaplek flour and corn grits-mocaf flour. Furthermore, this study also aimed to explore the impact of extrusion variables, specifically the ratio of corn grits to cassava flour/mocaf flour, extruder barrel temperature, and initial moisture content, on the physical properties of the extrudate.

2. MATERIALS AND METHODS

2.1. Materials

The main ingredient used was corn grits obtained from CV Surya Grain Indonesia. Mocaf flour and gaplek flour were obtained from Rumah Singkong Bantul (Selopamioro, Bantul, Yogyakarta Special Region, Indonesia). Corn grits, mocaf flour, and gaplek flour were sieved using mesh-24, mesh-84, and mesh-84 sieves, respectively.

Table 1. Proximate composition of corn grit, mocaf flour, and gaplek flour

Composition	Corn grits	Mocaf flour	Gaplek flour
Moisture (%)	12.17 ± 0.19	14.04 ± 0.08	12.27 ± 0.02
Ash (%)	0.55 ± 0.01	0.62 ± 0.01	1.69 ± 0.04
Total protein (%)	6.54 ± 0.06	1.00 ± 0.05	1.81 ± 0.05
Fat (%)	1.06 ± 0.02	0.12 ± 0.01	0.44 ± 0.02
Crude fiber (%)	0.32 ± 0.04	0.39 ± 0.03	0.99 ± 0.08
Carbohydrate (%)	79.36 ± 0.25	83.83 ± 0.16	82.79 ± 0.09

*The data is represented as average ± standard deviation

2.2. Material Preparation

Material preparation was carried out by mixing corn grits and mocaf flour/gaplek flour (0%; 10%; 20% w/w ratio of mocaf or gaplek flour to corn grits) using a stand mixer (OSSEL OS-HLM7A, Indonesia). Certain amount of water was added during the mixing process to adjust the material moisture content to 14%, 16%, and 18%.

2.3. Extrusion Process

A SYSLG-IV (Shandong Saibainuo Machinery, China) laboratory-scale twin screw extruder was used to perform the extrusion process. The barrel of the extruder is equipped with four temperature-adjustable heaters. The first three heater of the barrel was set at 40°C, 50°C, and 100°C, respectively, while the fourth heater was varied at 120°C /130°C /140°C. The extruder screw, feeder, and cutter speeds were kept fixed at 1200, 900, and 360 rpm, respectively, throughout all experiments. The extruder was equipped with a 6 mm opening diameter circular die. The resulting extrudate was then air-cooled. After cooling, the extrudate was kept in a polypropylene bag containing silica gel prior to further analysis.

2.4. Extrudate Physical Properties Analysis

2.4.1. Expansion Ratio

The extrudate expansion ratio was measured by comparing the diameter of the extrudate to the die diameter following the method in (Agathian *et al*., 2015). Extrudate diameter was measured using digital calipers (Sigmat Digital, Indonesia). The extrudate expansion ratio was computed by dividing extrudate diameter (mm) by die diameter (mm).

2.4.2. Particle Density

Particle density measurements were made by taking the dimension of the extrudate (diameter, length) using digital calipers and weighing the extrudate using an analytical balance (Shimadzu AUW220, Japan). Particle density of the extrudate was calculated by dividing the mass of the extrudate by the volume of the extrudate, assuming cylindrical shape (Equation 1) (Lazou *et al*., 2007).

$$\text{Particle density } (\text{g/cm}^3) = \frac{4 \times \text{weight of extrudate (g)}}{\pi \times \text{diameter (cm)}^2 \times \text{length (cm)}} \tag{1}$$

2.4.3. Moisture Content

Extrudate moisture content is measured by drying the extrudate sample at 105°C for 24 hours until the sample mass is constant following the thermogravimetric method (AOAC, 2005).

2.4.4. Color

Extrudate color was determined using a colorimeter (TES 135A, Taiwan) with the CIE LAB color space. The L* value indicates lightness, with a value of 0-100 (black to white). The b* value reflects the degree of yellow to blue color, with positive b* values indicate a stronger yellow color (Kaur *et al*., 2015).

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

WAI and WSI measurements were carried out following the method in Minweyelet *et al*. (2021) with modifications. A total of 1 g of pulverized extrudate was suspended in 8 ml of distilled water then homogenized using a vortex mixer (DLAB MX-S, China) and left to rest for 30 minutes at room temperature. The sample was then centrifuged at 3000 x g for 5 minutes. The supernatant was then decanted into an aluminum dish and dried at 105°C. The mass of solids from the supernatant was then used in the calculation of WSI (Equation 2). The remaining sediment was weighed and used in the WAI measurement (Equation 3).

$$WSI\ (\%) = \frac{mass\ of\ dissolved\ solid\ in\ supernatant\ (g)}{mass\ of\ dry\ sample\ (g)} \times 100 \tag{2}$$

$$WAI\ (g/g) = \frac{mass\ of\ water\ sediment\ (g)}{mass\ of\ dry\ sample\ (g)} \tag{3}$$

2.4.6. Hardness

Hardness of extrudate was expressed as the maximum stress value. Measurement of hardness was done using a Brookfield CT-3 texture analyzer fitted with a 2 mm diameter TA39 probe. The probe speed was set at pretest speed 2 mm/s, test speed 1 mm/s, and return speed 1 mm/s. The target depth was set at 7 mm. The load (g) value was then converted to stress (N/mm²).

2.4.7 Proximate Analysis

Proximate analysis included ash content, total protein content, fat content, crude fiber content, and carbohydrate content measurement. Measurement of ash content (%wb) was done by gravimetric method. Determination of fat content (%wb) was done using Soxhlet method. Total protein content (%wb) was measured using the Kjeldahl method (6.25 conversion factor). Crude fiber content was determined by gravimetric method. Difference method was used to calculate the carbohydrate content.

2.4.7 Statistic Analysis

Two-way analysis of variance (ANOVA) was used to determine the effects of corn-gaplek flour/mocaf flour grit ratio, initial moisture content, and temperature of the barrel on extrudate physical properties at the 5% significance level using IBM SPSS 27. ANOVA analysis was followed by post hoc analysis using the Tukey test. Principal component analysis (PCA) was also performed to characterize the extrudates made from corn grits-gaplek flour blend and corn grits-mocaf flour blend. ANOVA analysis was performed using IBM SPSS Statistics 27 and PCA was performed using Minitab 21 (Minitab, LLC., USA).

3. RESULTS AND DISCUSSION

Table 2 summarizes the effect of single factors (mocaf or gaplek flour portion, initial moisture content, and barrel temperature) and their interactions on on the physical properties of extrudates including expansion ratio (ER), particle density (PD), extrudate moisture content (MC), water absorption index (WAI), and water solubility index (WSI).

Table 2. Effect of treatments on the physical properties of extrudates

Factor and interaction	ER	PD	MC	L*	b*	WAI	WSI	H
Corn grits-mocaf flour extrudate								
A (ratio of mocaf or gaplek flour)	+	+	+	+	+	NS	+	+
B (initial moisture content)	+	+	+	+	+	+	+	+
C (barrel temperature)	+	+	+	+	+	+	+	NS
A×B	+	NS	+	+	+	NS	+	NS
B×C	+	+	+	NS	+	+	NS	NS
Corn grits-gaplek flour extrudate								
A (ratio of mocaf or gaplek flour)	+	+	NS	+	+	NS	+	NS
B (initial moisture content)	+	+	+	+	+	+	+	+
C (barrel temperature)	NS	NS	NS	+	+	+	NS	NS
A×B	NS	NS	+	+	NS	NS	+	NS
B×C	NS	NS	NS	+	+	+	+	NS

Note: ER: expansion ratio; PD: particle density; MC: extrudate moisture content; WAI: water absorption index; WSI: water solubility index; H: hardness. [+] indicate significance with $p < 0.05$; [NS] no significance ($p > 0.05$)

3.1. Expansion Ratio

Expansion is one of the most important parameters in determining the quality of extruded snacks (Sudhakar *et al.*, 2021). The expansion ratios of corn grits-mocaf flour and corn grits-gaplek flour extrudates were not significantly different ($p > 0.05$). The expansion ratio ranged from 2.74-3.86 for mocaf flour - corn grit extrudates while 2.60-3.87 for gaplek flour - corn grit extrudates (Figure 1). Increasing the ratio of mocaf flour or gaplek flour tended to decrease

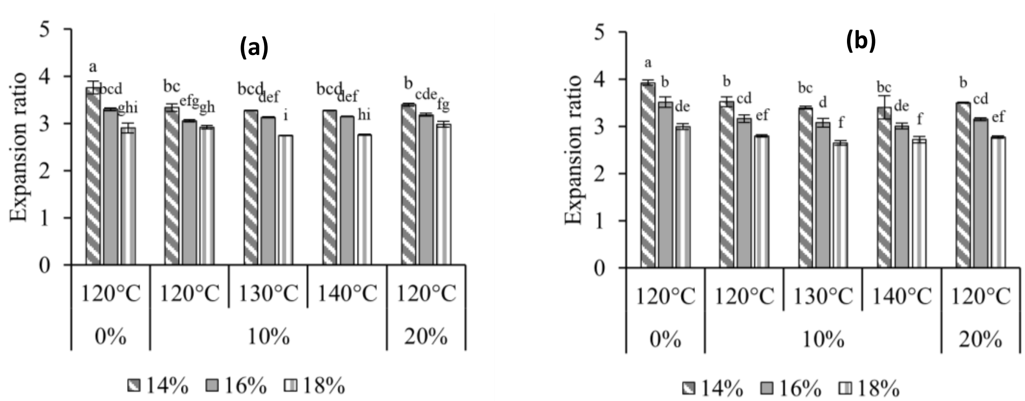


Figure 1. Expansion ratio of extrudates under varying ratios of flour to corn grits, initial moisture content, and barrel temperature conditions: (a) corn grits-mocaf flour extrudate, and (b) corn grits-gaplek flour extrudate

the expansion ratio of the extrudate. In general, cassava starch contains about 80% amylopectin and corn starch contains 75% amylopectin (Yu & Moon, 2022; Zhu, 2015). The addition of mocaf/cassava starch increases the ratio of amylopectin:amylose which can cause air bubbles to grow initially and then collapse resulting in an under-expanded extrudate due to the weak structure (Fiorda *et al*., 2015).

Increase in moisture content was found to lower the expansion ratio of the corn grit-mocaf flour/ gaplek flour blend extrudate. Increasing the amount of water in the material reduces the material viscosity in the extruder, therefore the formed bubbles collapsed after exiting the die, lowering the expansion ratio (Kantrong *et al*., 2018). Higher barrel temperature also tended to decrease the expansion ratio of the extrudate. The decrease in expansion ratio can be caused by excessive softening of the material as well as potentially causing degradation of the starch structure, hence it cannot withstand high vapor pressure and collapsed (Altan & Maskan, 2012).

3.2. Particle Density (PD)

Particle density (PD) of an extrudate is inversely proportional to its expansion ratio (Berrios *et al*., 2004). The PD values corn grit-mocaf flour and corn grit-gaplek flour extrudates showed no significant difference ($p>0.05$). PD increased as the mocaf/gaplek flour ratio and initial moisture content increased (Figure 2). The increase in fiber content due to the addition of mocaf and cassava flour tends to rupture the air bubbles before they form in the material, causing the extrudate expansion to decrease and the density to increase (Shirazi *et al*., 2020). High moisture content causes a plasticizing effect on the starch matrix in the extruder thus decreasing the elasticity of the matrix and causing a decrease in expansion (Mohammed *et al*., 2024). In addition, increasing barrel temperature tended to increase PD in extrudates with 10% mocaf flour ratio from 0.15-0.29 g/cm³. This could be due to the fact that after a certain critical temperature (depending on the starch type and moisture content), dextrinization, structural degradation, and over softening occur (Korkerd *et al*., 2016).

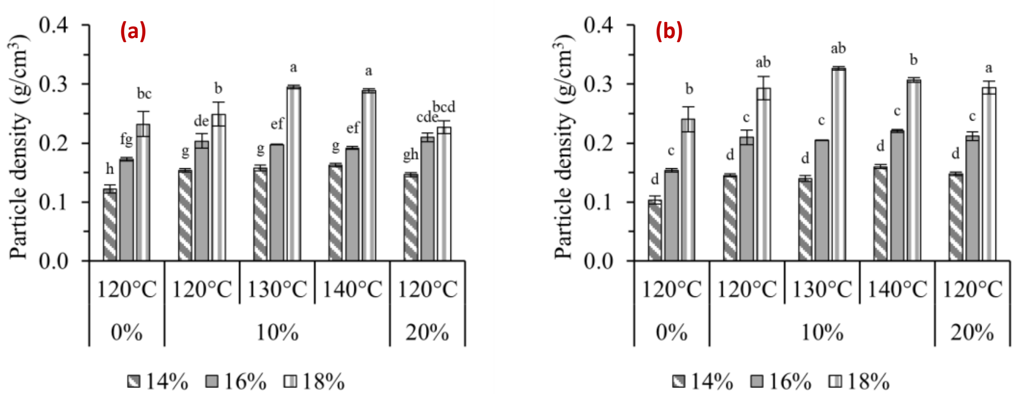


Figure 2. Particle density extrudates under varying ratios of flour to corn grits, initial moisture content, and barrel temperature conditions: (a) corn grits-mocaf flour extrudate, and (b) corn grits-gaplek flour extrudate

3.3. Moisture Content

The moisture content of the extrudates obtained ranged from 7.8 - 12.3% for corn grit - mocaf flour extrudates and 8.1 - 12.5% for corn grit - gaplek flour extrudates (Figure 3). There was no significant difference of moisture content between corn grits-mocaf flour extrudates and corn grits-gaplek flour extrudates ($p>0.05$). Initial moisture content positively affected extrudate moisture content. This was also found by Sharifi *et al.* (2021) on corn grit-based extrudates. However, barrel temperature negatively influenced moisture content of the extrudate. At higher temperatures, there is an increase in water evaporation as the extrudate exits the die (Boakye *et al*., 2022). Increasing the mocaf flour/ cassava flour ratio tended to decrease the moisture content of the extrudate. At low mocaf or gaplek flour ratios, the protein content from corn becomes higher. Protein can affect the distribution of water in the material matrix, causing more water to hydrate the material and leading to an increase in extrudate moisture content (Altan & Maskan, 2012).

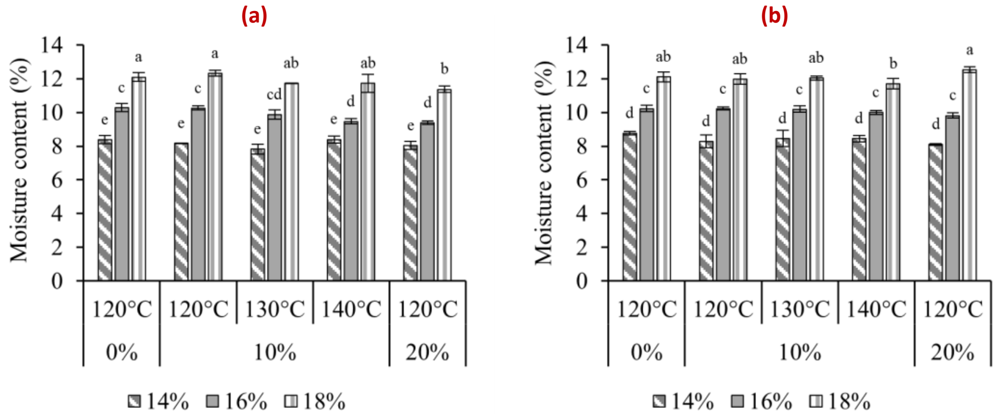


Figure 3. Moisture content under varying ratios of flour to corn grits, initial moisture content, and barrel temperature conditions: (a) corn grits-mocaf flour extrudate, and (b) corn grits-gaplek flour extrudate

3.4. Color

The extrudate color of corn grits-mocaf flour and corn grits-gaplek flour did not differ significantly ($p > 0.05$). The increase in L value and decrease in b^* due to the increase in the mocaf or gaplek flour ratio is attributed to the fact that the mocaf flour and cassava used are white in color so that the color of the extrudate tends to be lighter (closer to white) (Table 3). Barrel temperature had a positive effect on L and b^* of mocaf-flour corn grits extrudate but a negative effect on L and b* of cassava-flour corn grits extrudate.

Table 3. Lightness (L) and yellowness (b^*) of extrudates

Treatment	Corn grits-mocaf flour		Corn grits-gaplek flour	
	L	***b****	***L***	***b****
R0% T120°C A14%	85.62 ± 2,25^{e}	59.34 ± 0.63^{b}	96.06 ± 0.27^{a}	52.57 ± 0.41^{def}
R10% T120°C A14%	88.50 ± 0.90^{de}	42.36 ± 1.51^{h}	88.03 ± 0.44^{bc}	51.50 ± 1.78^{efg}
R20% T120°C A14%	92.12 ± 0.81^{a}	47.14 ± 0.90^{efg}	88.39 ± 0.95^{e}	46.15 ± 0.09^{cdef}
R10% T130°C A14%	94.43 ± 1.13^{ab}	50.90 ± 0.27^{efg}	81.34 ± 1.62^{f}	53.58 ± 0.14^{efg}
R10% T140°C A14%	94.24 ± 0.49^{abc}	50.74 ± 0.30^{g}	77.87 ± 1.96^{bc}	51.04 ± 0.92^{hi}
R0% T120°C A16%	79.56 ± 1.97^{f}	56.46 ± 0.67^{bcd}	94.97 ± 0.38^{a}	57.63 ± 2.88^{abc}
R10% T120°C A16%	85.37 ± 0.81^{e}	49.62 ± 2.42^{fg}	88.01 ± 1.22^{bc}	53.29 ± 1.28^{cdef}
R20% T120°C A16%	86.81 ± 0.56^{abc}	41.56 ± 3.49^{cde}	88.54 ± 0.15^{cd}	49.40 ± 0.82^{bcd}
R10% T130°C A16%	92.24 ± 0.58^{abc}	54.31 ± 0.16^{def}	85.62 ±0.77^{bc}	56.55 ± 1.53^{i}
R10% T140°C A16%	93.26 ± 0.53^{e}	53.91 ± 0.09^{h}	88.25 ± 0.84^{bc}	43.14 ± 1.67^{fgh}
R0% T120°C A18%	74.34 ± 0.60^{g}	64.09 ± 1.81^{a}	90.42 ± 0.17^{b}	62.19 ± 1.49^{a}
R10% T120°C A18%	85.72 ± 1.40^{e}	58.74 ± 3.10^{bc}	86.15 ± 1.31^{cd}	58.49 ± 2.84^{ab}
R20% T120°C A18%	91.37 ±1.01^{bcd}	49.48 ± 0.77^{ab}	84.04 ± 0.75^{cd}	55.00 ± 1.37^{ghi}
R10% T130°C A18%	91.14 ± 0.67^{cd}	59.69 ± 0.67^{ab}	85.71 ± 0.80^{bc}	47.38 ± 0.70^{ghi}
R10% T140°C A18%	90.81 ± 0.45^{abcd}	59.60 ± 0.06^{fg}	87.87 ± 1.01^{de}	47.66 ± 1.57^{bcde}

R: ratio of mocaf flour or gaplek flour to corn grits; T: barrel temperature; A: initial moisture content. Different superscripts within the same column signify statistical differences ($p < 0.05$)

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

Water absorption index (WAI) is a measure of the volume occupied by starch after swelling under excess water conditions and can serve as an indicator of gelatinization (Kanojia & Singh, 2016). The WAI of the extrudates ranged from 5.99-6.75 for corn grits-mocaf flour extrudates and 5.73-6.84 for cassava flour-corn grits extrudates (Figure 4). The WAI between two types of extrudates was significantly different ($p<0.05$). The WAI values for both corn grits-mocaf flour extrudates and corn grits-gaplek flour extrudates did not show a particular trend with the mocaf/gaplek flour ratio, initial moisture content, and barrel temperature. However, higher initial moisture content treatment tended

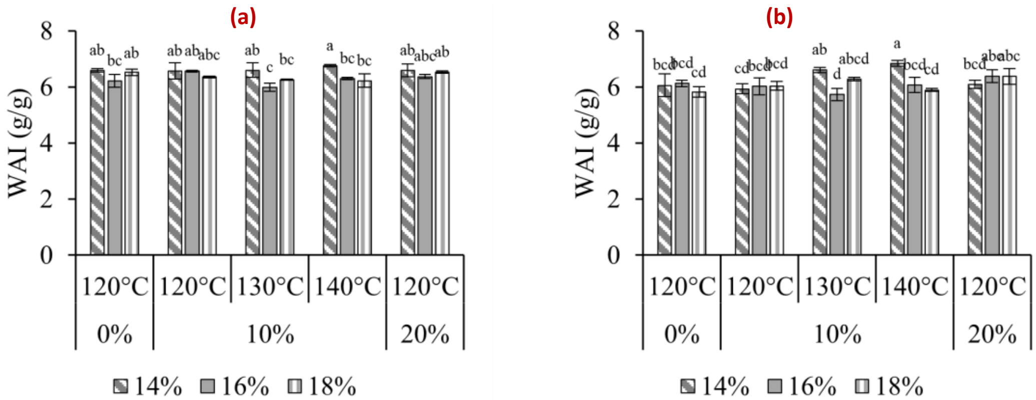


Figure 4. WAI for extrudates under varying ratios of flour to corn grits, initial moisture content, and barrel temperature conditions: (a) corn grits-mocaf flour extrudate, and (b) corn grits-gaplek flour extrudate

to produce extrudate with lower WAI. This could be due to the fact that there is a plasticizing effect by the water inside the extruder, therefore reducing the starch cooking degree (Sharma *et al*., 2017). At 14% moisture content, the extrudate WAI of corn grits-mocaf flour and corn grits-gaplek flour tended to increase as the increase in barrel temperature. This could be due to more heat availability, thus increasing starch gelatinization level (Huang *et al*., 2022). Similar phenomenon was reported by Seth *et al*., (2015) when developing extrudates based on yam-corn-rice.

Water solubility index (WSI) is a measure of the degradation of starch molecules that occurs during the extrusion process, increasing the amount of water-soluble polysaccharides (Dalbhagat *et al*., 2019). The WSI was ranging from 2.52-6.38% for the corn grits-mocaf flour extrudate and 2.41-5.16% for the corn grits-gaplek flour extrudate (Figure 5). WSI of corn grits-mocaf flour extrudate was significantly different with the WSI of corn grits-gaplek flour extrudate ($p<0.05$). For the corn grit-mocaf flour extrudate, the flour ratio from 0% to 10% decreased the WSI of the extrudate, but the WSI increased at the 20% ratio. The increase in WSI at a ratio of 10-20% may be due to the fact that small-granular cassava starch is more sensitive to heat, which can increase WSI (Tatsabong & Ryu, 2018). In addition, the high amylopectin content in cassava causes the matrix cohesivity to decrease and favors starch degradation during extrusion and causes an increase in WSI (Chisenga *et al*., 2019).

Initial moisture content also affected WSI of the extrudate. Extrudate WSI tended to decline as the increase in initial moisture content of the material. Increased moisture content can result in reduced starch degradation resulting in less water-soluble starch and lower extrudate WSI value (Patel *et al*., 2016). On the other hand, barrel temperature had a positive influence on extrudate WSI. This could be due to increased extrusion temperature causing degradation of starch resulting in more water-soluble carbohydrates and thus increasing the WSI (Kaur *et al*., 2015; Peksa *et al*., 2016).

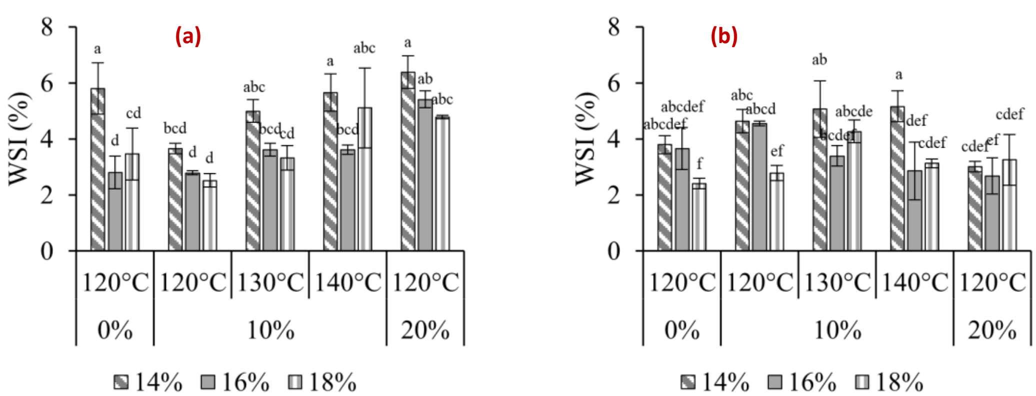


Figure 5. WSI for extrudates under varying ratios of flour to corn grits, initial moisture content, and barrel temperature conditions: (a) corn grits-mocaf flour extrudate, and (b) corn grits-gaplek flour extrudate

3.6. Hardness

Texture is an important parameter in extruded snacks. The hardness of corn grits-mocaf flour and corn grits-gaplek flour extrudates were significantly different ($p < 0.05$). Hardness ranged from 0.40 to 1.70 N/mm² for corn grits-mocaf flour extrudates and 0.39 to 2.53 N/mm² for corn grits-gaplek flour extrudates (Figure 6). It was found that the hardness of corn grits-mocaf flour extrudates was influenced by the ratio of mocaf flour and initial moisture content, while that of a corn grits-gaplek flour extrudates was only influenced by initial moisture content ($p < 0.05$) (Table 2). Initial moisture content had a positive influence on extrudate hardness. The increase in hardness can be due to the fact that inside the extruder, water acted as a lubricant, thus reducing energy dissipation and causing inhibited bubble growth and producing a dense extrudate (Zambrano *et al*., 2022). Moreover, the addition of mocaf flour tended to increase the hardness of the extrudate because it caused a decrease in extrudate expansion.

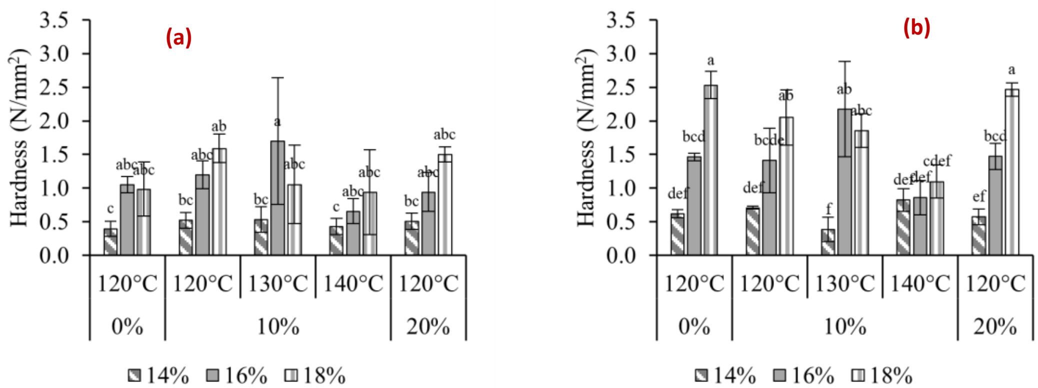


Figure 6. Hardness for extrudates under varying ratios of flour to corn grits, initial moisture content, and barrel temperature conditions: (a) corn grits-mocaf flour extrudate, and (b) corn grits-gaplek flour extrudate

3.7. Proximate Analysis

The results of proximate analysis of the extrudate can be seen in Table 4. The addition of mocaf flour and cassava flour increased the ash content significantly ($p < 0.05$). The increase in ash content due to the addition of gaplek flour was higher than that of mocaf flour. This increase is likely to indicate higher mineral availability in the extrudate (Altaf *et al*., 2021).

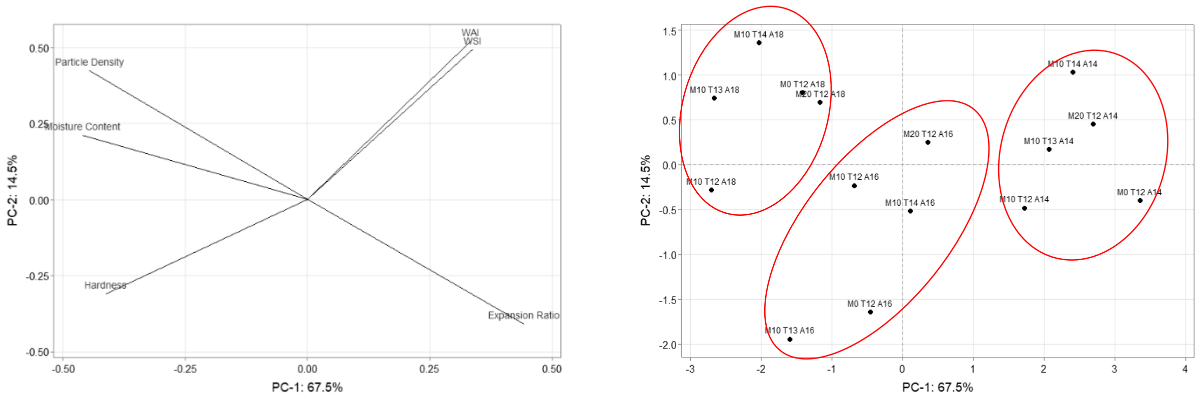
Table 4. Proximate composition of extrudate at 120°C barrel temperature and 14% initial moisture content

Sample	Ash (%)	Total protein (%)	Fat (%)	Crude fiber (%)	Carbohydrate (%)
100% corn grits	0.62 ± 0.01a	7.65 ± 0.04d	0.12 ± 0.00c	0.39 ± 0.03a	90.10 ± 0.26ab
10% mocaf	0.65 ± 0.02ab	7.26 ± 0.04b	0.13 ± 0.01c	0.33 ± 0.01a	90.48 ± 0.26bc
20% mocaf	0.67 ± 0.01b	6.64 ± 0.03a	0.10 ± 0.01b	0.64 ± 0.05b	90.89 ± 0.09c
10% gaplek	0.85 ± 0.01c	7.54 ± 0.02c	0.18 ± 0.01d	0.39 ± 0.05a	89.82 ± 0.07a
20% gaplek	0.84 ± 0.02c	6.60 ± 0.03a	0.07 ± 0.01a	0.39 ± 0.02a	90.95 ± 0.05c

*Data is represented as average ± standard deviation; Different superscripts within same column signify significant differences with $p < 0.5$

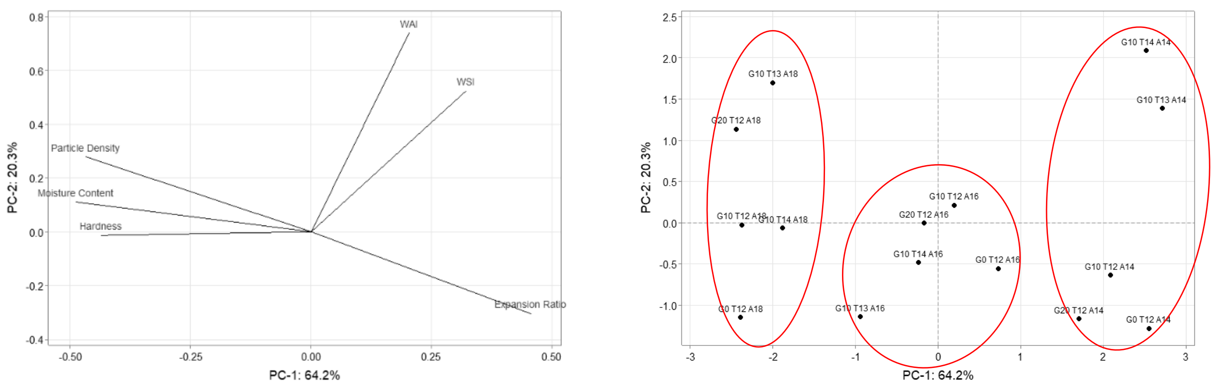
3.8. Extrudate Characterization

The relationships between the physical characteristics of the corn grits-mocaf flour and corn grits-gaplek flour extrudates were shown using principal component analysis (PCA) (Figure 7 and 8). In the PCA for corn grits-mocaf flour extrudates, the first two PCs could explain 82% of the variance (Figure 7) while for corn grits-gaplek flour extrudates, the first two PCs could explain 84.5% of the variance. Loading plots show the relationship between the physical properties of the extrudates. Particle density, moisture content, and hardness tended to cluster on the negative X-axis and opposite to the expansion ratio on the positive X-axis for both types of extrudates (Figures 7a and 8a). Extrudates located to the right of the Y-axis tended to have higher expansion ratio, WAI, and WSI than those extrudates



(a) (b)

Figure 7. PCA analysis of corn grits-mocaf flour extrudate at various treatments (a) loading plot, and (b) score plot



(a) (b)

Figure 8. PCA analysis of corn grits-gaplek flour extrudate at various treatments (a) loading plot and (b) score plot. (M = mocaf flour, G = gaplek flour, T = barrel temperature, A = initial moisture content)

located to the left of the y-axis. From the PCA score plot (Figures 7b and 8b), it can be seen that extrudates treated with 14% moisture content have higher expansion ratio, WAI, and WSI and lower particle density, hardness, and moisture content than extrudates treated with 16% and 18% moisture content. These parameters are related to consumer acceptance of extruded snacks. Consumers prefer extrudates that are both crunchy and well-expanded. Therefore, low initial moisture content treatment is more suitable to produce extrudates that are favored by consumers.

4. CONCLUSION

The use of a higher mocaf flour/gaplek flour ratio can produce denser, harder, and less expanded extrudates that have higher moisture content and L value. An increase in initial moisture content caused an increase in particle density, extrudate moisture content, and hardness and caused a decrease in expansion ratio, WAI, and WSI. Barrel temperature had a positive effect on WAI and WSI but a negative effect on expansion ratio and extrudate moisture content. The production of extrudates is prioritized at 14% moisture content to ensure that the extrudates have preferable physical properties. Addition of mocaf flour or gaplek flour up to 20% can still be tolerated to produce acceptable extrudates.

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