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The Effect of Sodium Tripolyphosphate and Guar Gum on Physical Characteristics of Analog Rice from Gaplek Flour

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ABSTRACT

Gaplek flour is a processed product of cassava preservation abundant during the harvest season in Lampung Province. The high carbohydrate content in cassava facilitates the processing of gaplek flour into carbohydrate-rich food source, such as analog rice. Therefore, this study aimed to investigate the effect of adding STPP and guar gum on the formulation of analog rice made from 70% gaplek flour and 30% corn flour. Analog rice was produced using the extrusion method with a twin-screw extruder. The results showed that the addition of STPP did not affect water absorption characteristics. The solubility of rice in deep water also decreased with increasing amounts of STPP and guar gum. Meanwhile, guar gum significantly increased water absorption and reduced the solubility of rice in water. The degree of gelatinization decreased with the addition of both materials. The addition of 0.3-0.5% STPP and 0.5-2% guar gum had no significant effect on hardness, stickiness, elasticity, and cohesiveness of analog rice prepared using a cooker.

Keywords: Analog rice; gaplek flour; guar gum; sodium tripolyphosphate; warm extrusion

INTRODUCTION

Analog rice is made from tubers and cereals, processing a shape and nutritional composition similar to paddy rice (Winarti et al., 2018). It serves as an alternative food diversification product to reduce dependence on paddy rice. Analog rice can be produced from various carbohydrate sources, such as cassava (Suswadi, 2014), sorghum, corn (Budi et al., 2017), taro (Pudjihastuti et al., 2019), sweet potatoes, or a mixture of various flour. Cassava is a tuber widely cultivated in Lampung Province (Mardliyah & Supriyadi, 2018) and commonly processed into various food products, such as gaplek. This gaplek can be made by soaking fresh cassava in water for 2 days to undergo spontaneous fermentation. The water is changed every 12 hours throughout the soaking period. The fermented cassava is subsequently dried and ground into powder (Pasca et al., 2022), serving as a raw material for various processed foods like cakes, noodles, or others. Gaplek flour has a brownish-white color with a distinctive aroma (Yenny, 2018). Besides

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being a primary ingredient for processed foods, it can also be used as a raw material for producing analog rice due to high carbohydrate content, reaching 76.21% (Wijana et al., 2011).

Analog rice can be produced through two common processes, namely granulation (Rahmawati et al., 2019) and extrusion (Budi et al., 2017). Extrusion technology offers various advantages, such as high capacity and the ability to complete the grain-making process in a single device (Kusumayanti et al., 2023). This facilitates the production process and handling of raw materials and products. In the formulation of materials through extrusion, binding agents are required to maintain the shape of grains throughout the manufacturing process and during cooking. Gelatinized starch and hydrocolloids can serve as binding agents during production. However, due to the limitations of the extruder, extrusion process is conducted at a temperature below 70°C. At this temperature, the starch in the materials does not undergo complete gelatinization, preventing its function as a binding agent in analog rice. Guar gum is a type of hydrocolloid that can act as a stabilizer by binding other polymers containing water molecules to form a crosslinking structure. The resulting structure has improved stability and compactness (Sharma et al., 2018). STPP as an inorganic salt also has the ability to form strong bonds due to the presence of disulfide. These bonds can increase the stability of materials, specifically when cooked. The collapse of rice when cooked can be related to the cooking loss characteristics of noodles. Both the addition of guar gum (Aminullah et al., 2020; Ratnawati & Afifah, 2018a) and STPP (Obadi et al., 2022) can reduce cooking loss in noodles. This is also expected to produce a stronger rice structure free from collapse when cooked, resulting in high stickiness. Therefore, the current study aimed to investigate the effect of STPP and guar gum on water absorption, solubility, gelatinization degree, cooking, and texture of analog rice produced from gaplek and corn flour.

METHODS

Materials

The raw materials used included gaplek flour of kasesart variety obtained from Anak Tuha, Central Lampung, and corn flour obtained from PT Matahari Corn Mills, Kediri. Gaplek flour was prepared by soaking peeled cassava for 24 hours, and subsequently cut into small sizes. The cassava was dried and soaked again for another 6 hours, grated and pressed to reduce the moisture content to 30-35% (Yulianto et al., 2022). This pressed product was referred to as gaplek flour, and other food ingredients used in the current study were food-grade sodium tripolyphosphate (Aditya Birla Chemicals, Thailand Ltd.) and food-grade guar gum (Barrel O Slime, India Ltd.). The chemicals used for analysis purposes were of pro-analysis quality from Sigma Aldrich (St. Louis, MO, USA). Furthermore, the equipment included a 40-mesh sieve (Indonesia), sieve shaker (Indonesia), steam boiler (Indonesia), LT70L twin-screw extruder (Shandong Light, China Ltd.), and drying oven (Indonesia).

Figure 1. Twin screw extruder

Analog Rice Making

Analog rice was produced from a mixture of gaplek and corn flour in a ratio of 70:30. The addition of corn flour increased the amount of amylose in the materials, and the appropriate ratio between amylose and amylopectin could reduce the stickiness of the resulting rice. The 40 mesh corn flour was blended with gaplek flour and some water using a mixer until a mixture moisture content of 32.5±2.5% was obtained (Yulianto et al., 2022). Furthermore, the content was adjusted to obtain analog rice with a gelatinization degree of approximately 50%, as evidenced by non-sticky grains exiting the extruder. The mixture was subsequently steamed for 20 minutes.

The flour mixture was supplemented with STPP at 0.3% and 0.5% concentrations (Obadi et al., 2022; Zhao et al., 2022) as well as guar gum at 0.5% and 2% (Rafiq et al., 2016) after steaming. These concentrations can significantly reduce cooking loss in noodles. The materials were blended using a mixer and conditioned to 30-35% moisture content. The added water during mixing and preconditioning before entering the extruder could affect the gelatinization degree of analog rice. Water addition was adjusted to obtain a specific gelatinization degree, resulting in analog rice with the desired characteristics. Gaplek and corn flour mixture was fed into a barrel inlet through the feeder. The process conditions used were modified based on the process of making analog rice from gaplek flour without adding extra food ingredients (Yulianto et al., 2022). These modifications were made to optimize the extruder to produce grains resembling paddy rice and non-sticky. The process conditions are shown in Table 1.

Table 1. Extrusion process conditions in the production of analog rice

Process parameters	Process conditions
Motor rotation speed of the feeding screw	5-6 Hz
Motor rotation speed of the screw extruder	7.5-8.5 Hz
Temperature at the extruder tip	45-50°C
Rotation speed of the dough-cutting blade	22-23 Hz

The extrusion product was dried in an oven at 50 °C until the moisture content reached ≤12%. The physical characteristics of the dried grains were subsequently examined.

Moisture Content Test

Gravimetric moisture content measurement was conducted using the method adopted from (Fitri et al., 2017). Approximately 3 g of the sample was placed in a pre-dried and weighed porcelain dish. The dish containing the sample was dried at 105 °C for 6 hours, cooled in a desiccator for 15 minutes, and re-weighed. These processes were repeated until a constant weight was obtained. The moisture content was calculated using Equation 1.

$$Moisture\ content\ (\%) = \frac{initial\ weight - final\ weight}{initial\ weight} \times 100\% \tag{1}$$

Water Absorption Test

Water absorption measurement was conducted using the method adopted from Yudanti & Waluyo(2015). Approximately 25 g of analog rice (WA) was soaked in hot water (75 °C) for 5 minutes and drained using a sieve for 2 minutes. Rice was reweighed (WB) to determine the increase in weight after soaking in hot water. Water absorption was calculated using Equation 2.

$$Water\ absorption\ (\%) = \frac{wb - wa}{wa} \times 100 \tag{2}$$

Description: WA = sample weight before soaking (g) and WB = sample weight after soaking (g)

Solubility Index Test

The solubility index was determined based on the amount of particles that dissolved when rice was added to a specific amount of water. It can be calculated by comparing the weight of the soluble particles after drying with the initial sample weight (Equation 3) (Yousf et al., 2017).

$$Water\ solubility\ index\ (\%) = \frac{soluble\ particle\ weight}{sample\ weight} \times 100 \tag{3}$$

Gelatinization Degree Test

The gelatinization degree was measured using the amylose-iodine complex method (Baks et al., 2007). Approximately 40 mg of the sample was dissolved in 50 mL of 0.15 M KOH and stirred with a magnetic stirrer for 15 minutes. The solution was subsequently centrifuged at 2500 rpm for 15 minutes. After centrifugation, 1 mL of supernatant was mixed with 9 mL of 0.017 M HCl and 0.1 mL of iodine (1 g iodine and 4 g potassium iodide dissolved in 100 mL of distilled water). The absorbance of the sample was measured with a spectrophotometer at a wavelength of 600 nm (A1). The same procedure was repeated using 0.40 M KOH solution to dissolve all amylose in the sample, followed by neutralization with 0.045 M HCl. The resulting absorbance was measured at a wavelength of 600 nm (A2). The gelatinization degree was calculated by determining the ratio of absorbance A1 to A2 multiplied by 100%.

Analog Rice Cooking Method

Approximately 100 g of the sample was soaked in water for 5 minutes and drained. The soaked rice was placed in a rice cooker with 150 mL of boiling water. The 'cook' button was activated, and the rice was subsequently stirred and left to stand for 10 minutes to be fully cooked.

Rice Texture Test

Analog rice was prepared using a specific method. A portion was cooked for a maximum of 15 minutes and selected for hardness, stickiness, cohesiveness, and elasticity measurements. Rice texture was assessed using a Universal Testing Machine CT3 (Brookfield). The instrument was configured with a pre-test of 1 mm/s, a test speed of 0.5 mm/s, and a post-test of 2 mm/s (Kurniasari et al., 2020). The sample was compressed to 60% using a 38.1 mm diameter aluminum cylinder probe. The test was conducted on 10 grains of rice sample with 5 repetitions.

RESULTS AND DISCUSSION

Moisture Content of Analog Rice

The moisture content significantly impacts the ashelf life of food products. Water serves as a medium for both microbiological and biochemical damage, where the higher the moisture content, the faster the damage reactions. Table 2 shows that the moisture content of the 4 independent variables ranged from 10.20% to 11.81%. These values did not show significant differences at a 95% confidence level. Analog rice with moisture content within this range is considered to fulfill standards. According to quality standards, the maximum moisture content for paddy rice is 14%, which can also be applied to analog rice. Analog rice becomes more susceptible to mold contamination when moisture content exceeds 14% (Sede et al., 2015). Therefore, the processing should ensure a decrease in moisture content to less than 14%.

The addition of guar gum in noodle formulation (Ratnawati & Afifah, 2018a) and STPP in the modification process of suweg starch (Setiyoko & Yuliani, 2021) tended to reduce the final product's moisture content. This reduction could be attributed to the ability of both materials to interact with other molecules and increase water-binding capacity. Guar gum tends to interact more readily with polar solvents due to its hydroxyl groups. When added to hydrated starch, electrostatic interactions occur between the high electronegativity atoms (O atoms) in hydrated starch molecules and the hydroxyl groups, forming strong hydrogen bonds (Thakur et al., 2018). The starch-guar gum molecules formed have more hydroxyl groups compared to native starch molecules, leading to increased water-binding capacity. Similarly, the reaction between the phosphate groups of STPP and the hydroxyl groups of hydrated starch can facilitate the starch's water-binding ability (Wang et al., 2019). Water in bound form cannot be considered as product's moisture content when tested using gravimetric methods. The gravimetric moisture content test only measures the amount of evaporable water when the product is heated (free water), excluding water in bound positions (Bradley, 2010) (Sede et al., 2015). Bound water is more resistant to release than free water during drying processes. Therefore, the addition of guar gum and STPP tends to decrease moisture content.

Water Absorption of Analog Rice

Water absorption is related to the ability of rice grains to absorb or bind water during the cooking process. The greater the water absorption, the larger the size of the cooked rice grains. The amount of water absorbed is influenced by the composition of rice grain constituents. Data analysis using ANOVA at a significance level of $\alpha=0.05$ showed that the addition of 0.3% STPP did not affect water absorption, while 0.5% caused a decrease.

The high amylopectin content in gaplek and tapioca flour, approximately 50%, could increase water absorption. The addition of phosphate, capable of improving porosity, could increase water absorption in starch granules (Yustiawan et al., 2019). The heating of materials with high water absorption can facilitate gelatinization. During gelatinization, starch, specifically amylopectin found in the amorphous structure, leaches from starch granules and undergoes retrogradation or forms crystalline structures after cooling (Aini et al., 2016). The more crystalline structures, the less the starch's ability to bind water (Retnaningtyas & Putri, 2014).

Guar gum consists of mannose backbones bonded by α-1,4 glycosidic, and galactose groups bound to α-1,6 glycosidic as side chains. These galactose groups contain free hydroxyl groups capable of forming hydrogen bonds with other molecules. Hydroxyl groups become available with increased usage of guar gum, playing a crucial role in forming hydrogen bonds with water molecules. Guar

Table 2. Physical characteristics of analog rice from gaplek flour

Parameter	Type and level of additional food ingredients				
	Blank	STPP (%)		Guar gum (%)	
		0.30	0.50	0.50	2.00
Moisture content (%)	10.89±0.76^{a}	11.81±0.54^{a}	10.20±0.21^{a}	10.99±1.09^{a}	10.47±0.04^{a}
Water absorption (%)	78.18±1.22^{bc}	77.80±1.58^{abc}	72.83±2.99^{a}	76.39±0.02^{ab}	81.92±2.43^{c}
Solubility index (%)	10.88±0.33^{b}	10.26±1.22^{b}	7.74±1.54^{ab}	4.95±1.74^{a}	9.59±0.08^{b}
Gelatinization degree (%)	60.35±0.64^{c}	53.60±0.28^{a}	54.69±0.24^{ab}	59.95±4.03^{bc}	56.15±1.77^{abc}

Description: Different letters in the same row show significant differences ($p \leq 0.05$)

gum can form intermolecular bonds when water binds to other molecules such as starch, facilitating its usage as a stabilizer and thickener (Sharma et al., 2018). It can be added to food in various concentrations, depending on the requirements and standards set by the Food and Drug Monitoring Agency (BPOM). Guar gum and amylose molecules react after gelatinization of starch and subsequent cooling (Ratnawati & Afifah, 2018b). The addition of guar gum can increase water absorption capacity during rehydration. For instance, the addition of 2% guar gum to corn flour noodle formulation can increase water absorption capacity from 6 to 6.86 g/g (Udachan & Sahoo, 2017). Similarly, Rafiq et al. (2016) reported that the addition of 2% guar gum to horse chestnut flour noodle formulations increased water absorption by 16%.

Water Solubility Index of Analog Rice

The solubility index of analog rice refers to the amount of particles dissolved in water during the cooking process. Analysis showed that the concentration of STPP increased with a reduction in the solubility index. Based on Duncan's test, 0.5% STPP concentration could significantly decrease the solubility of the materials. The result was consistent with Yustiawan et al. (2019), stating that the modification of starch with 1% STPP decreased solubility from 46.6% to 40%. Phosphate groups tended to form cross-links, acting as bridges between starch molecules. Stable cross-links could facilitate granule stability, making starch less readily dispersed in water (Retnaningtyas & Putri, 2014).

Guar gum, a hydrocolloid, is often added to non-wheat noodle production to improve cooking quality and sensory characteristics. The addition of 2% guar gum can reduce cooking loss by 3.53% in noodles made from horse chestnut flour (Rafiq et al., 2016). The cooking loss parameter in noodles is closely related to the amount of solids lost during cooking. Moreover, the ability of guar gum to form high-viscosity colloid dispersions results in cohesive and compact dough, reducing dough solubility in water during cooking (Mudgil et al., 2014).

Gelatinization Degree

The gelatinization degree describes the extent amylose and amylopectin in the materials undergo gelatinization. Analysis showed that the addition of 0.3% and 0.5% STPP could reduce the gelatinization degree of analog rice. This reduction was attributed to an increase in the initial gelatinization temperature of the materials and the addition of STPP. The heating process weakened the hydrogen bonds of amylose and amylopectin molecules, facilitating water penetration into the granules. During gelatinization, amylose leached out of the granules, while the crystalline structure containing amylopectin became increasingly fragile (Breuninger et al., 2009). The initial gelatinization temperature varied for each type of starch and was influenced by starch granule size, fat content, protein content, and modification processes. For instance, palado seeds with high starch content had a gelatinization temperature of 70.00 °C. Cross-linking modification of palado seed starch could increase this temperature to 72.05 °C (Rahman et al., 2017). The addition of phosphate to flour could also increase the initial temperature due to the formation of cross-links with hydroxyl groups, requiring higher energy to decompose (Adicandra & Estiasih, 2016). With a higher initial gelatinization temperature, at the same process temperature, the amount of gelatinized amylose and amylopectin decreased, leading to a lower gelatinization degree of materials.

Analysis showed that the addition of guar gum could reduce the gelatinization degree of the resulting analog rice, although at an insignificant rate. The result was consistent with Gong et al. (2021), stating that the addition of hydrocolloids like 0.3-0.5% guar gum did not affect the amount of energy or enthalpy required for the melting of starch molecules. However, increasing the concentration of guar gum to more than 1% could increase enthalpy. The rise in enthalpy corresponded with the number of starch molecules forming cross-links with hydrocolloids, reducing starch mobility. This could make starch gelatinization more challenging and require high energy. Consequently, the achievable gelatinization degree of the materials during the heating process could also decrease.

Texture Characteristics of Analog Rice

The hardness of analog rice could be attributed to the retrogradation process of starch and secondary bonds formed between amylose and other molecules. Starch retrogradation is the reformation of amylose and amylopectin bonds after gelatinization. A higher level of amylose leaching during the analog rice-making process could lead to increased retrogradation. Results showed that the addition of 0.3-0.5% STPP did not significantly affect the hardness of analog rice made from a mixture of gaplek and tapioca flour. Changes in hardness were closely related to alterations in the gelatinization profile of the materials. The addition of STPP facilitated the formation of phosphate cross-links, thereby increasing peak viscosity (Faridah & Thonthowi, 2020). A higher viscosity typically resulted in lower product hardness. This was because the leaching amylose was not excessive during the heating process, and retrogradation only extended

Table 3. Texture profile of analog rice from a mixture of gaplek and corn flour

Parameter	Type and level of additional food ingredients				
	Blank	STPP (%)		Guar Gum (%)	
		0.30	0.50	0.50	2.00
Hardness (N)	37.93±12.82^{a}	46.38±12.81^{ab}	33.58±18.13^{a}	46.33±0.28 ^{ab}	42.93±12.96^{a}
Stickiness (Nmm)	50.74±74.71^{a}	114.98±11.45^{a}	116.95±4.5^{ab}	82.03±18.71^{ab}	127.94±12.34^{b}
Cohesiveness (N)	0.11±0.04^{a}	0.12±0.06^{a}	0.10±0.01^{a}	0.14±0.01^{a}	0.1221±0.02^{a}
Elasticity index	0.77±0.00^{ab}	0.78±0.02^{abc}	0.84±0.09^{bc}	0.76±0.00^{a}	0.79±0.02^{abc}

Description: Different letters in the same row show significant differences ($p \leq 0.05$)

to the formation of amylose cross-links. However, retrogradation should not only include the interaction of leaching amylose cross-links but also the formation of secondary bonds with other molecules. These bonds could contribute to the increased hardness of analog rice (Budi et al., 2017). A decrease in the hardness of materials formulated with the addition of STPP was reported by Zhao et al. (2022). Although there was no significant decrease, the addition of 0.3% STPP to a semi-dry noodle formulation reduced the hardness level from 3776.99 g to 3643.03 g. Conversely, the addition of STPP could significantly increase the elasticity of noodles from 16.85 to 20.13 g. Based on analysis, the stickiness of rice increased with the addition of STPP. This could be attributed to the absence of strong bonds in leaching amylose, prevalent on the surface. During the cooking process of rice, the surface amylose leached out and dissolved in water, thereby increasing the stickiness of the product. A positive correlation between rice stickiness and solubility index was evident, as an increase in solubility index was consistently followed by an increase in stickiness (Mayasti et al., 2018).

The hardness of analog rice formulated with the addition of 0.5% and 2% guar gum tended to increase. However, the statistical results from Duncan test at α = 5% showed an insignificant value. The increased hardness of analog rice with the addition of guar gum could be attributed to gum's ability to reduce the dispersion of amylose during starch gelatinization. The results corresponded with (Widaningrum & Haliza, 2022), that the addition of 1% guar gum to noodle formulation did not significantly increase hardness. Moreover, stickiness and elasticity remained significantly unchanged with the addition of 1% guar gum. The addition of more than 1% could reduce the retrogradation ability of rolled oats. This reduction corresponded with the inability of amylose to form intermolecular structures with other amylose molecules due to its binding with guar gum. The bond between amylose and guar gum tended to decrease starch's ability to absorb water. As a result, during the cooking process, the starch might not fully gelatinize, leading to a harder grain texture. On the other hand, the addition of guar gum could increase stickiness by facilitating water absorption and viscosity (Gong et al., 2021).

CONCLUSION

In conclusion, analog rice formulated with 0.5% STPP and 0.5% guar gum had the lowest water solubility index but high water absorption. These characteristics facilitated the production of rice with larger grain sizes and firmer shapes, as the starch remained undissolved in water. In terms of texture, the hardness, stickiness, cohesiveness, and elasticity of rice were not significantly different from analog rice made from gaplek and corn flour without the addition of STPP and guar gum.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest related to the results of this study with other parties.

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