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Physicochemical and Organoleptic Properties of Analog Rice from White Corn Flour and Canna Starch with Glycerol Monostearate Addition

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Abstract

Indonesia's reliance on rice as a staple food is challenged by declining harvested areas, highlighting the need for alternative carbohydrate sources. Analog rice made from white corn flour (WCF) and canna starch (CS), with glycerol monostearate (GMS) as a texture modifier, offers a potential solution to promote food diversification and reduce dependence on conventional rice. The purpose of this study was to determine the ideal WCF–CS ratio and GMS level. This study employed a completely randomized design with two factors: the WCF to CS ratios (60:40, 70:30, 80:20) and the addition of GMS (2%, 3%, 4%), each replicated three times. Analog rice was prepared through a process of mixing, steaming, extrusion, and drying. Physicochemical properties (moisture, ash, protein, carbohydrate, starch, amylose, amylopectin, rehydration, bulk density, and cooking time), as well as sensory attributes, were analyzed using analysis of variance (ANOVA) followed by Duncan's multiple range test (DMRT) at a 5% significance level. The formulation containing 70% WCF, 30% CS, and 3% GMS yielded the most desirable product with 0.67 g ml^{-1} of bulk density, 98.27% of rehydration ability, 207.67 seconds of cooking time, 7.02% of moisture, 0.46% of ash, 0.24% of fat, 6.47% of protein, 85.82% of carbohydrate, 77.28% of starch, 26.45% of amylose, and 50.84% of amylopectin. The results of the organoleptic scores for color, taste, texture, and aroma were 3.12, 3.52, 3.84, and 3.60, respectively. This research highlights the potential of local carbohydrate sources such as corn and canna for analog rice production to support national food diversification.

Keywords: amylose content; cooking quality; corn-based analog rice; food diversification; sensory properties

INTRODUCTION

Rice is the primary staple food and the main source of carbohydrates for most Indonesians. In 2022, Indonesia's population reached 273,879,750, with an average annual rice consumption of 139.15 kg per person, or approximately 0.4 kg per day (Statistics of Indonesia, 2023). This high dependency on rice has raised concerns, particularly as the harvested rice area has decreased by 2.45%. It is projected to continue declining due to land conversion for infrastructure and other non-agricultural purposes (Statistics of Indonesia, 2023). Nevertheless, Indonesia is rich in alternative carbohydrate sources such as sorghum, sago, corn, and tubers, including sweet potato, cassava, canna, arrowroot, yam, and taro. Despite their availability, these commodities remain underutilized in daily diets (Nadhifa et al., 2025). Previous studies have emphasized the potential of these crops in food diversification programs,

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for example, analog rice formulated from tuber-based starches.

Analog rice, also known as artificial rice, is produced from non-rice ingredients. The combination of carefully selected raw materials and proper processing techniques can yield a product that closely resembles conventional rice (Liu et al., 2022). Analog rice formulated from tuber-based starches has been shown to exhibit distinct sensory and physicochemical properties, reflecting the characteristics of the raw materials used (Liu et al., 2022; Nadhifa et al., 2025). Nadhifa et al. (2025) demonstrated that analog rice from tuber-based ingredients exhibits unique colors, aromas, and flavors depending on the source material.

White corn has been identified as a promising ingredient due to its high carbohydrate (85.64%) and protein content (8.01%) (Zulfa et al., 2023). It is preferred over yellow corn because its kernel color produces analog rice with an appearance closer to conventional rice (Islam et al., 2018). Formulations combining white corn flour with sago starch (Sumardiono et al., 2021) or combined with red beans and agar as a binding agent have yielded analog rice with acceptable sensory quality and improved nutritional value.

The main starch components relevant to analog rice production are amylose and amylopectin. White corn flour contains approximately 17.73% amylose (Noviasari et al., 2013). Amylose significantly influences rice texture, as higher amylose levels tend to produce a firmer, less sticky texture (Tao et al., 2019). Therefore, additional ingredients are often incorporated to achieve a desirable texture that is neither too sticky nor too dry. Mishra et al. (2012) reported that canna starch contains approximately 42.50% amylose and 50.90% amylopectin, which contributes to a moderately firm analog rice texture and less sticky grains.

In addition to selecting appropriate raw materials, processing aids such as glycerol monostearate are crucial. Glycerol monostearate functions as a food-grade emulsifier, improving the texture of analog rice by preventing it from becoming too soft or too dry (Noviasari et al., 2013; Prakaywatchara et al., 2017). Noviasari et al. (2013) demonstrated that incorporating 2% glycerol monostearate can yield analog rice with a texture that is neither excessively soft nor overly dry. Water is another essential ingredient, comprising approximately 50% of the mixture, as it facilitates dispersion of compounds and starch gelatinization. Additionally, 2% oil (based on total weight) is typically added to prevent dough adhesion to the extruder and to ensure uniform extrudate separation.

However, studies focusing on the combined application of white corn flour and canna starch with glycerol monostearate are limited. To address this research gap, the present study investigates the combined use of white corn flour and canna starch with glycerol monostearate, with the hypothesis that this formulation can improve both the physicochemical and sensory characteristics of analog rice. The objective of this study is to evaluate the effect of different ratios of white corn flour and canna starch and levels of glycerol monostearate addition on the quality of analog rice.

MATERIALS AND METHOD

This research was conducted at the Food Processing Technology, Food Analysis, and Organoleptic laboratories of the Department of Food Technology, Universitas Pembangunan Nasional "Veteran" Jawa Timur, and the Quality Testing Laboratory at Brawijaya University.

Materials

White corn (*Zea mays ceratina* L) were obtained from e-commerce platforms, white canna starch purchased from Ladang Lima store, and glycerol monostearate (GMS), palm oil, sodium metabisulfite, benzene, hexane solvent, K_2SO_4, H_2SO_4, HgO, $Na_2S_2O_3$, H_3BO_3, methylene red indicator, methylene blue indicator, citric acid, HCl, NaOH, ethanol, CH_3COOH, KIO_3, Luff-Schoorl solution, starch solution, iodine solution, pure amylose, and aquadest were obtained from CV. Vanjaya Chemical.

Preparation of analog rice

The mixture consisted of white corn flour (WCF) and canna starch (CS) at ratios of 60:40, 70:30, and 80:20, with GMS added at 2%, 3%, and 4% of the total mixture, and water comprising 50% of the blend. All materials were blended in the given proportions, then mixed for 5 minutes with a dry mixer to achieve a uniform consistency. The homogenous mixture was subsequently steamed for 15 minutes at 80 to 85 °C. After steaming, the mixture was extruded into granules using an extruder set to a temperature of 70 to 90 °C. These granules were then dried in a cabinet dryer for 6 hours at 50 °C, yielding analog rice. This preparation method aligns with previous studies on analog rice production, which also employed sequential processes of mixing, steaming, extrusion, and drying (Florie and Kusumayanti, 2024).

Physicochemical analysis

The analysis of this study covers raw material analysis (WCF and CS), which entails determining proximate and carbohydrate content by difference, starch, amylose, and amylopectin. The resulting analog rice product was then subjected to physicochemical analysis, which included the determination of moisture content, ash, fat (Soxhlet), protein (Kjeldahl) (AOAC, 2006), carbohydrate by difference (Mishra et al., 2012), starch, amylose spectrophotometric method, and amylopectin (AOAC, 2005), rehydration capability (Kurniasari et al., 2020), bulk density (Sumardiono et al., 2021), cooking duration (Noviasari, 2013), and organoleptic (hedonic) test (Pramono et al., 2021).

Sensory analysis

The sensory quality of the analog rice samples was evaluated through a hedonic sensory test. A total of 40 semi-trained panelists were recruited from the Department of Food Technology. Panelists were screened for their availability, interest in sensory evaluation, and absence of allergies to corn or starch-based foods. Analog rice was cooked under standardized conditions (1:2 sample-to-water ratio, using an electric rice cooker) to ensure uniformity across treatments. Samples were served warm (50 to 55 °C) in identical, three-digit-coded containers and presented in a randomized order to minimize bias. Panelists were instructed to cleanse their palates with water between evaluations of each sample. The following sensory attributes were assessed such as color or appearance, aroma, texture, taste, and overall acceptability. Each attribute was evaluated using a 5-point hedonic scale, where 1 represented extremely dislike and 5 represented extremely like. Sensory sessions were conducted in a controlled sensory evaluation laboratory with neutral lighting and adequate ventilation to minimize external influences.

Data analysis

The data obtained were analyzed using analysis of variance (ANOVA) at a 5% significance level, followed by Duncan's multiple range test (DMRT) at the same significance level. Data analysis was performed using Minitab 19 for Windows.

RESULTS AND DISCUSSION

Characteristics of raw materials

The initial analysis of WCF (Table 1) revealed a moisture content of 6.98%, an ash content of 0.33%, 0.21% fat, 7.14% protein, 85.34% carbohydrates, 61.28% starch, and 54.06% amylopectin, all of which were lower than those reported in the literature. In contrast, the amylose concentration of 19.11% was higher than previously reported values (Setyowati and Purwani, 2021). The glycemic index (GI) of analog rice was not determined experimentally in this study. However, considering the amylose content of 19.11%, which is moderately high, the analog rice may potentially exhibit a lower GI compared to conventional polished rice, as higher amylose content has been associated with slower starch digestibility (Pereira et al., 2021). The initial examination of CS (Table 1) revealed a moisture of 8.34%, carbohydrate of 90.11%, starch of 86.26%, and amylose of 26.42%, all of

Table 1. Chemical characteristics of WCF and CS

Parameter	WCF		CS	
	Analysis	Literature	Analysis	Literature
Moisture (%)	6.98±0.04	12.12(a)	8.34±0.06	17.94(b)
Ash (%)	0.33±0.06	0.12(a)	0.44±0.04	0.32(b)
Fat (%)	0.21±0.02	0.40(a)	0.14±0.03	0.04(b)
Protein (%)	7.14±0.08	10.44(a)	0.97±0.03	0.26(b)
Carbohydrates (%)	85.34±0.22	89.04(a)	90.11±0.25	99.40(b)
Starch (%)	73.17±0.19	61.28(c)	86.26±0.11	93.30(b)
Amylose (%)	19.11±0.18	17.73(a)	26.42±0.15	42.40(b)
Amylopectin (%)	54.06±0.23	57.66(c)	59.84±0.21	50.90(b)

Source: a = Noviasari et al. (2013), b = Harmayani et al. (2011), c = Sahilatua et al. (2019)

which were lower than previously reported values. Similar studies on *Canna edulis* starch reported slightly higher starch and amylose contents, depending on cultivar and extraction method (Thitipraphunkul et al., 2003). Meanwhile, the ash (0.44%), fat (0.14%), protein (0.97%), and amylopectin (59.84%) in this study were higher than previously reported, which may be attributed to cultivar differences and environmental conditions (Tanaka et al., 2023).

The variances in raw material analysis results compared to the literature can be attributed to several factors, including variations in the white corn variety used, growing area, climate, and raw material processing procedures. This finding is similar to those of Sandhu et al. (2005), who claim that variances in WCF results are determined by elements such as variety, growing climate, soil conditions during cultivation, and other influencing factors, all of which can affect the chemical composition of the material.

Physicochemical properties

Moisture, ash, protein, carbohydrate, starch, amylose, and amylopectin

The research found no significant influence ($p > 0.05$) of adding GMS to the quantity of WCF and CS on moisture, ash, protein, carbohydrate, starch, amylose, and amylopectin in the analog rice. However, a significant difference was observed in the treatments involving the WCF:CS ratios (Table 2), whereas the GMS treatment showed no significant difference (Table 3).

The moisture (Table 2) ranged from 6.94 to 7.13%. The increasing proportion of WCF and the decreasing proportion of CS resulted in a significant reduction in the moisture of analog rice, as a decreasing proportion of CS resulted in lower moisture. The starch composition of analog rice influences its moisture content, as higher starch levels typically result in greater water retention. It is due to starch's capacity to bind water, which is greater for CS than for WCF. The preliminary analysis revealed that the starch content of CS was 86.26%, whereas that of WCF was 73.13%. As a result, CS can bind more water, increasing moisture. Donmez et al. (2021) state that starch, as a macromolecular component, is capable of absorbing water.

Table 3 shows that the moisture ranged from 7.01 to 7.05%. It indicates that increasing the addition of GMS did not significantly affect the moisture content, as it serves as a binding agent that retains water. Noviasari et al. (2017) stated that GMS can form a complex with amylose, creating an insoluble layer on the surface of the starch granules, which delays the transport of water to the granules and thereby reduces expansion, preventing the release of amylose (Kaur et al., 2005).

The ash (Table 2) ranged from 0.43 to 0.51%, indicating that raising the proportion of WCF while decreasing the proportion of CS resulted in a considerable reduction in the ash of the analog rice, because the ash of WCF (0.33%) is lower than that of CS (0.44%). Pérez and Lares (2005) revealed that CS contains a high concentration of mineral components, such as calcium, iron, and phosphorus, which contribute to an increase in ash content in the analog rice. The effect of GMS addition on ash, as shown in Table 3, ranged from 0.46 to 0.48%. It indicates that increasing the addition of GMS did not significantly affect the reduction of ash in the analog rice.

The protein (Table 2) ranged from 6.55 to 6.39%, indicating that increasing the proportion of WCF and decreasing the proportion of CS resulted in a significant increase in protein, because WCF has a higher protein (7.14%) than CS (0.77%). This result is lower than that reported by Liu et al. (2022), which indicates that WCF has a protein content of up to 8.01%. As a result, the protein of the analog rice increases with the amount of WCF used. Table 3 shows the effect of GMS addition on protein, which varied from 6.44 to 6.49%, and did not significantly impact the protein content of the analog rice, as GMS does not contain protein.

The carbohydrate (Table 2) ranged from 85.70 to 85.84%. It indicated that increasing the proportion of WCF with lower carbohydrate content (85.34%) and decreasing the proportion of CS with higher carbohydrate content (90.11%) led to a significant reduction in carbohydrates. Therefore, a higher proportion of WCF can decrease the overall carbohydrate content of the analog rice. The same trend was observed in starch, amylose, and amylopectin levels. Likewise, for the effect of adding GMS.

Fat

The proportion of WCF and CS, with the addition of GMS, significantly affects ($p \leq 0.05$) the fat content of analog rice. Figure 1 shows that the increase in fat can be attributed to the higher proportion of WCF and the reduction of CS in the

Table 2. Effects of the varying proportions of WCF and CS on the physicochemical properties

WCF:CS	Moisture (%)	Ash (%)	Protein (%)	Carbohydrates (%)	Starch (%)	Amylose (%)	Amylopectin (%)
60:40	7.13±0.08^{c}	0.51±0.03^{c}	6.39±0.02^{a}	85.84±0.03^{c}	77.33±0.04^{c}	29.34±0.42^{c}	47.99±0.46^{a}
70:30	7.03±0.06^{b}	0.46±0.03^{b}	6.46±0.05^{b}	85.80±0.13^{b}	77.29±0.06^{b}	26.73±1.87^{b}	50.55±1.92^{b}
80:20	6.94±0.06^{a}	0.43±0.04^{a}	6.55±0.14^{c}	85.70±0.25^{a}	77.18±0.05^{a}	24.65±0.46^{a}	52.53±0.50^{c}

Note: Different notations in one column indicate significant differences ($p \leq 0.05$)

Table 3. Effects of GMS addition on the physicochemical properties

GMS addition (%)	Moisture (%)	Ash (%)	Protein (%)	Carbohydrates (%)	Starch (%)	Amylose (%)	Amylopectin (%)
2	7.01±0.29^{a}	0.48±0.13^{a}	6.44±0.30^{a}	85.82±0.33^{a}	77.25±0.22^{a}	27.23±6.99^{a}	50.02±6.77^{a}
3	7.03±0.27^{a}	0.47±0.12^{a}	6.47±0.23^{a}	85.78±0.21^{a}	77.26±0.23^{a}	26.84±7.25^{a}	50.43±7.04^{a}
4	7.05±0.31^{a}	0.46±0.13^{a}	6.49±0.18^{a}	85.74±0.12^{a}	77.28±0.23^{a}	26.66±7.04^{a}	50.62±6.83^{a}

Note: Different notations in one column indicate significant differences ($p \leq 0.05$)

formulation. WCF contains a relatively higher fat content (0.21%) compared to CS (0.14%), thus contributing more lipids to the final product. Furthermore, the addition of GMS, which is a lipid-based emulsifier, also contributed to the elevated fat levels. As the GMS concentration increased, its lipid contribution became more significant, leading to a measurable rise in the overall fat content of the analog rice.

Bulk density

When GMS was added, the proportions of WCF and CS had a significant effect ($p < 0.05$) on bulk density (Figure 2), which ranged from 0.34 to 0.79 g ml^{-1}. The lowest bulk density (0.34 g ml^{-1}) was observed at a 60:40 ratio of WCF to CS with 2% GMS, whereas the highest bulk density (0.79 g ml^{-1}) was recorded at an 80:20 ratio with 4% GMS. This upper value is close to the bulk density of conventional rice, which is approximately 0.82 g ml^{-1} (Qadir and Wani, 2023), suggesting that formulations rich in WCF with higher GMS levels can produce analog rice with packing properties similar to natural rice grains.

The increase in bulk density with higher WCF levels can be explained by the intrinsic densities of the raw flours: WCF has a higher bulk density (≈0.83 g ml^{-1}) than CS (≈0.72 g ml^{-1}). As a result, WCF contributes to a denser, less porous matrix during steaming and extrusion, whereas CS tends to expand more, resulting in greater porosity and lower bulk density. This finding is consistent with the results of Watcharatewinkul et al. (2009), who noted that higher bulk density indicates a more compact structure with fewer voids.

Additionally, the role of GMS is evident in further increasing bulk density across various formulations. The hydrophilic head groups of GMS bind water, enhancing starch gelatinization and allowing particles to consolidate more effectively. GMS also reduces interparticle friction, facilitating closer packing and void collapse, which results in denser granules. This effect has been observed previously, where GMS functioned primarily as a texture modifier by reducing stickiness and improving granule separation during extrusion (Kaur et al., 2005). However, the present study emphasizes its role in densification in combination with WCF, which has not been widely reported in earlier studies.

From a technological perspective, bulk density has essential implications for cooking quality.

Analog rice with higher bulk density (WCF-rich, 3 to 4% GMS) tends to absorb less water and requires a longer cooking time. In comparison, analog rice with lower bulk density (CS-rich, lower GMS) has greater water absorption capacity and shorter cooking time. These findings complement the work of Florie and Kusumayanti (2024), who demonstrated that process steps such as steaming and extrusion strongly influence structural compaction. They extend prior studies by highlighting the role of WCF–CS ratios and GMS levels in tuning rice-like density properties. Although instrumental hardness was not measured in this study, the relatively high rehydration ability (98.27%) and moderate bulk density (0.67 g ml^{-1}) suggest a softer cooked texture. Previous studies have reported a negative correlation between porosity and hardness in analog rice and extruded products (Zambrano et al., 2022).

Overall, the present study demonstrates that WCF content is the primary determinant of analog rice bulk density, while GMS addition enhances densification through water binding and structural compaction. Compared to previous studies that primarily emphasized sensory or textural attributes, research findings demonstrate the significance of formulation variables in achieving bulk density values comparable to those of conventional rice, thereby enhancing the technological and consumer acceptance potential of analog rice.

Rehydration capacity

The rehydration capacity of the analog rice varied between 97.93% and 98.54% (Figure 3). The ratio of 80:20 with 4% GMS addition had the lowest rehydration capacity, whereas the ratio of 60:40 with 2% GMS addition had the highest. It showed that the bulk density of rice rises with

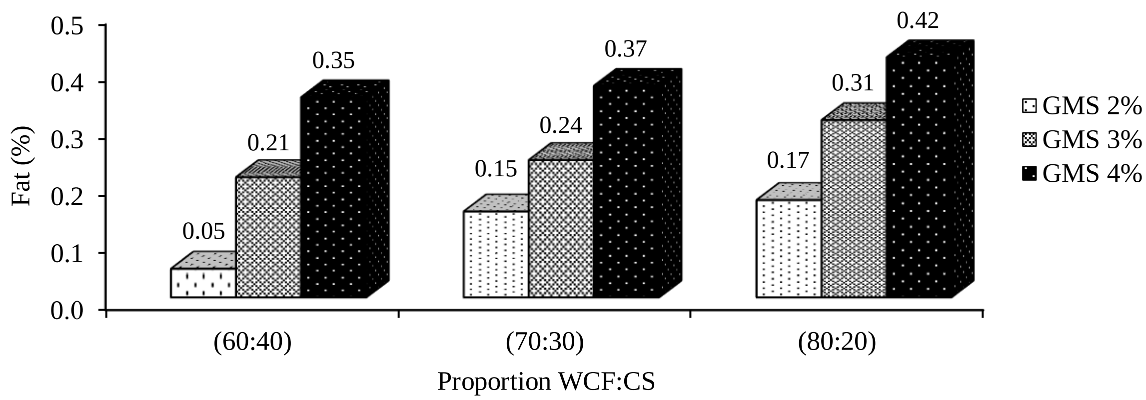

Figure 1. Effect of adding GMS and varying ratios of WCF to CS on the fat content of analog rice

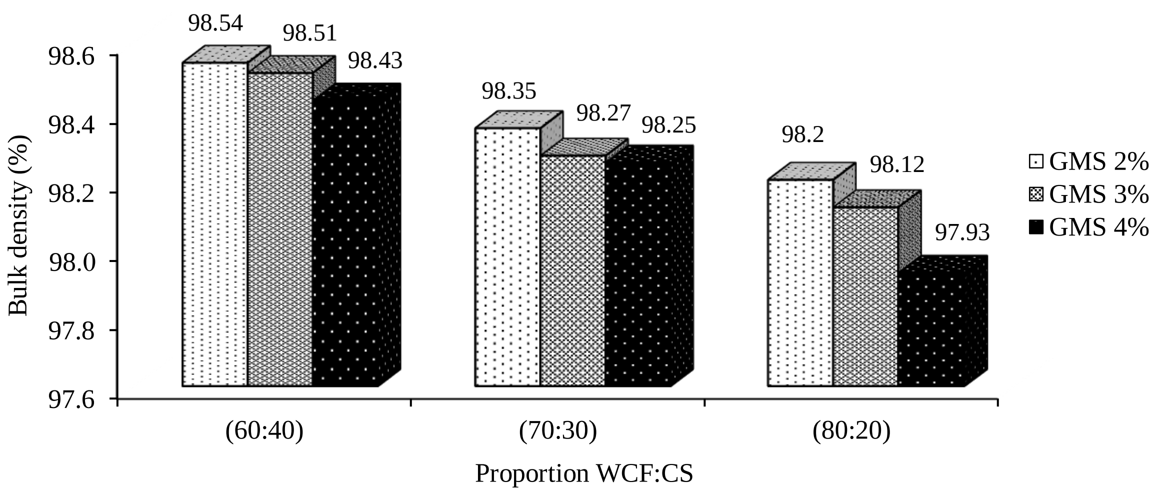

Figure 2. Effect of adding GMS and varying ratios of WCF to CS on the bulk density of analog rice

the percentage of CS. There are fewer air pockets or holes in the rice.

Figure 3 illustrates that the rehydration capacity of the analog rice decreases as the amounts of WCF and GMS increase, while the amount of CS decreases. It is related to the bulk density of the product. The bulk density of analog rice is higher when it has a larger percentage of WCF. The rice's ability to rehydrate is reduced when its bulk density rises because its air pockets or pores shrink.

The amylopectin of the analog rice is another factor contributing to the decline in rehydration capability. The amount of CS decreases as the amount of WCF increases, which lowers the amount of amylopectin and, in turn, the rehydration capacity. The reason is that amylopectin's ability to absorb and bind water decreases as its content increases, resulting in a decrease in its rehydration capacity.

According to Fitzpatrick et al. (2016), the type of raw materials used and their chemical makeup, including amylopectin, have an impact on a product's ability to rehydrate. The preliminary investigation indicates that CS has a greater amylopectin content (58.84%) than WCF (53.06%). Amylopectin can bind a substantial amount of water during the gelatinization process, as noted by Zainuddin (2016). The addition of GMS may further diminish the ability of analog rice to rehydrate. This is because GMS and amylose can combine to form a complex that inhibits water absorption. Hence, it decreases the capacity for rehydration.

Cooking time

A WCF to CS ratio of 60:40, combined with the addition of 2% GMS, produced the shortest cooking time (2 minutes 45 seconds). In comparison, the treatment with a ratio of 80:20 and the addition of 4% GMS produced the longest cooking time (4 minutes 15 seconds). The average cooking time ranges from 2.45 to 4.15 minutes (Figure 4).

Figure 4 illustrates how cooking time increases with rising WCF and decreasing CS proportions, as well as increased GMS addition. The product's rehydration capacity and density are both correlated with cooking time. Bulk density and water absorption are related to cooking time. The rice analog's ability to absorb water increases with decreasing bulk density, which in turn speeds up cooking, due to its higher bulk density (Figure 2) and lower rehydration capacity (Figure 3). Rice analog products with a larger percentage of WCF absorb water more slowly and take longer to cook.

The purpose of porous rice mimic grains is to absorb water into the final product, as noted by Rathnayake et al. (2022). Consequently, a product's cooking time decreases with its porosity, because GMS can create a compact and dense texture in the rice analog, which may reduce its ability to rehydrate. According to Yuwono et al. (2015), GMS can provide a texture that is less porous and more compact, which slows down the pace at which heat penetrates the rice analog and prolongs the gelatinization process. The product gets less porous as the amount of WCF

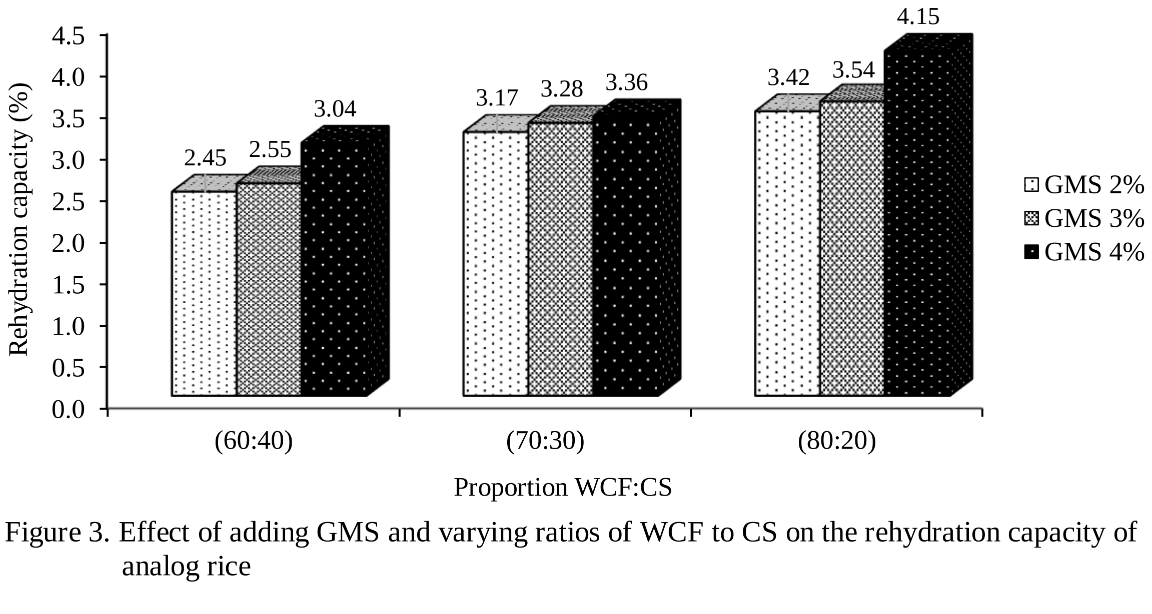

Figure 3. Effect of adding GMS and varying ratios of WCF to CS on the rehydration capacity of analog rice

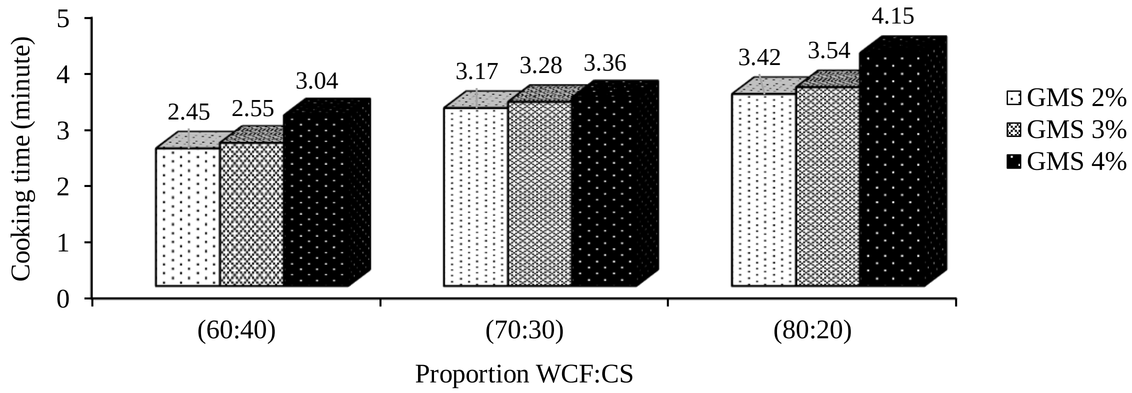

Figure 4. Effect of adding GMS and varying ratios of WCF to CS on the cooking time of analog rice

rises, which hinders heat entry and slows down the gelatinization process.

Organoleptic of analog rice

The sensory evaluation results indicate that variations in WCF, CS, and GMS levels did not significantly affect the color of analog rice ($p > 0.05$). This finding suggests that both WCF and CS, being naturally white and visually similar to polished rice, help maintain an appearance close to that of conventional rice. This outcome aligns with the results of Florie and Kusumayanti (2024), who reported that the color of analog rice is primarily determined by the inherent whiteness of the composite flours rather than by processing additives. However, unlike their study, which showed no apparent preference differences across treatments, the present study demonstrated that analog rice containing 80% WCF, 20% CS, and 2% GMS received the highest acceptance, indicating that a lower proportion of CS in the blend may better mimic the whiteness of rice preferred by consumers.

Flavor evaluation revealed that increasing the level of GMS led to a more bitter taste, which negatively influenced panelists' acceptance as shown in Table 4. The treatment containing 70% WCF, 30% CS, and 3% GMS received the highest flavor preference. It differs from Noviasari et al. (2013), who reported that the addition of 2% GMS improved texture without negatively impacting sensory flavor. The discrepancy may be due to differences in raw materials used, as WCF contains bioactive compounds that could interact with higher GMS levels, potentially altering taste perception.

Texture analysis revealed that the combination of 70% WCF, 30% CS, and 3% GMS yielded the highest preference rating, resulting in analog rice that was neither too soft nor excessively dry. These results are consistent with the findings of Kaur et al. (2005), who highlighted the role of GMS in preventing stickiness and improving granule separation during extrusion. However, while Kaur et al. (2005) emphasized the physical binding effect of GMS, the present study highlights its synergistic role with WCF and CS in balancing texture attributes, suggesting that the flour ratios are just as critical as emulsifier levels.

For aroma, the treatment containing 60% WCF, 40% CS, and 3% GMS received the highest preference. Since both WCF and CS have relatively neutral aroma profiles, they did not impart strong odors to the final product. This finding aligns with previous reports (Florie and Kusumayanti, 2024) that analog rice formulations using neutral base flours maintain an aroma similar to that of traditional rice. However, in contrast to studies using protein-rich flours such as soybean or canna (Jariyah and Vestra, 2023), which often introduce beany or off-flavors, the use of WCF and CS in the present work provided a more favorable sensory profile.

Overall, this study demonstrates that although color and aroma remain largely unaffected by formulation, optimizing the WCF–CS ratios with moderate levels of GMS plays a critical role in improving consumer acceptance of analog rice. The differences observed between this study and earlier publications may be attributed to the specific starch–protein composition of WCF and its interaction with GMS during extrusion.

The sensory evaluation results demonstrated that the panelists' acceptance of the product varied across the evaluated attributes.

Table 4. Descriptive sensory properties of analog rice

WCF:CS	GMS (%)	The quantity of rankings			
		Color	Taste	Texture	Aroma
60:40	2	120.0	143.0	96.0	124.5
60:40	3	115.0	101.5	123.0	139.0
60:40	4	128.0	97.0	112.0	128.0
70:30	2	124.5	130.5	130.5	130.5
70:30	3	105.0	154.5	149.5	149.5
70:30	4	126.5	107.0	139.0	108.0
80:20	2	160.5	141.5	119.5	123.5
80:20	3	125.0	118.5	129.0	108.0
80:20	4	120.5	131.5	127.5	115.0

Note: The higher the rank value, the more it is liked

On a 5-point hedonic scale, the mean scores were 3.12 for color, 3.84 for flavor, 3.68 for texture, and 3.60 for aroma. These findings indicate that all sensory attributes fell within the range of slightly liked to liked. Suggesting that the product was generally acceptable to the panelists. Among the evaluated attributes, flavor achieved the highest score (3.84), followed by texture (3.68) and aroma (3.60), while color obtained the lowest rating (3.12).

CONCLUSIONS

This study demonstrated that increasing WCF generally increased bulk density and decreased porosity, while higher CS content produced a more porous structure with greater water absorption capacity. The incorporation of GMS further enhanced structural integrity and water-binding properties, influencing both cooking quality and texture. The optimal formulation was obtained with 70% WCF, 30% CS, and 3% GMS, producing analog rice with desirable physicochemical characteristics (moisture 7.02%, ash 0.46%, fat 0.24%, protein 6.47%, carbohydrate 85.82%, starch 77.28%, amylose 26.45%, and amylopectin 50.84%), good functional properties (bulk density 0.67 g ml^{-1}, rehydration capacity 98.27%, cooking time 207.67 seconds), and favorable sensory acceptance (color 3.12, flavor 3.84, texture 3.68, and aroma 3.60). These findings suggest that analog rice produced from WCF–CS blends with GMS can serve as a promising alternative staple to support food diversification and reduce dependence on conventional rice. Future studies should investigate instrumental texture parameters (e.g., hardness) and glycemic index to provide a more comprehensive understanding of the nutritional and sensory implications of analog rice.

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