



Research article

Physicochemical properties of novel artificial rice produced from sago, arrowroot, and mung bean flour using hot extrusion technology



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HIGHLIGHTS

- Sago, arrowroot, and mung bean flour are the suitable material for artificial rice.
- Extrusion temperature influences the artificial nutritional rice significantly.
- The consumers reported that artificial rice product has been accepted as rice substitution.

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ABSTRACT

Due to high rice consumption, food insecurity can negatively impact health; hence, food diversification is considered an appropriate solution for achieving national food security. Artificial rice production using local natural resources will support food sustainability in Indonesia. Sago, arrowroot tuber, and mung bean flours were the main ingredients for producing artificial rice using the hot extrusion method. The effects of composite flour composition and extrusion temperatures on the nutritional value (carbohydrate, protein, fat, and fiber), morphological structure (scanning electron microscopy analysis), thermal stability (differential scanning calorimetry analysis), and acceptability of artificial rice were investigated in this study. The results showed that the best composition was obtained when using a combination of 50% (w/w) sago flour, 30% (w/w) arrowroot tuber flour, and 20% (w/w) mung bean flour. The results of chemical analysis showed that the best artificial rice in this study contained 11.18% water content, 80.27% carbohydrates, 5.14% protein, 0.46% fat, and 5.14% crude fiber. The product contained sufficient fiber and carbohydrate content to be an appropriate staple food. The best extrusion temperature was 85 °C. Moreover, the differential scanning calorimetry profiles showed that artificial rice began undergoing physical changes at approximately 100 °C. Importantly, the color, texture, aroma, and taste of the cooked artificial rice were accepted by consumers.

1. Introduction

Rice is a primary food for more than 50 % of the world's population (World Rice Production, 2019) (Mbanjo et al., 2020), including Japan (Kobayashi et al., 2018) and Indonesia (Aprillya et al., 2019). Rice is a stable human food crop and one of the most important in developing countries (Priya et al., 2019). Rice is cultivated in many countries and can grow in wet environments that other crops cannot tolerate (Saleh et al., 2019). Rice is a model species for crop research due to its relatively small genome and rich genetic diversity (Hanafiah et al., 2020). However, rice consumption and human dependency on rice are high,

initiating food insecurity. Food insecurity is a critical concern in fulfilling the availability and sustainability of food with sufficient nutritional content for humans (Abrams et al., 2020), and can cause negative impacts on health (Thomas et al., 2019). Meanwhile, food security can be seen as access the safe and sufficient food with nutritional content all year round (Gassner et al., 2019) (Savary, 2020). Agricultural production must be increased with high yields and efficiency of resource use to meet the challenges of ensuring food security and environmental sustainability (Guo et al., 2017). Food production and circular food system intensification could be part of future food security solutions (Vågsholm et al., 2020).

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Food diversification is an alternative to achieving national food security (Pudjihastuti et al., 2019). To this end, the Indonesian government implemented a food diversification program in 1974 (Budijanto and Yuliana, 2015). Unfortunately, the program provided unsatisfactory results to increase rice import and the price of rice. Therefore, artificial rice production has become attractive to many researchers. Artificial or mechanized rice production has responded to rural labor shortages and increased labor costs, where commercial agriculture has replaced it (Fukai et al., 2019). Artificial rice is defined as non-paddy rice that has the general appearance of rice and is produced from local resources with high levels of carbohydrates, such as potatoes, cassava, corn, and grains (Sumardiono et al., 2014) (Machmur et al., 2011). Carbohydrates are formally defined as compounds that contain carbon, hydrogen, and oxygen in the ratio of 1:2:1 (Ludwig et al., 2018). In this study, sago, arrowroot, and mung bean flours was used to produce the artificial rice due to some good reasons. Sago flour is one of main ingredients due to its high level of carbohydrates and affordable price (Kamal et al., 2007). Meanwhile, arrowroot (mostly Marantaceae) are large perennial herbs found in tropical forests (Nogueira et al., 2018) that have a high starch content with differentiated characteristics and high commercial value (Souza et al., 2019). Arrowroot flour is also a carbohydrate source and has a low glycemic index so that convenient for consumption by certain people (Lestari et al., 2017) (Sholichah et al., 2019). Further, mung beans are ingredient which have a high level of protein and good resource of vitamin (B, C, K) and minerals (potassium, manganese, copper, magnesium, zinc) (Olaleye et al., 2020).

Artificial rice can be produced by either the granulation (Katsuya et al., 1971); (Kurachi, 1995) or extrusion method (Koide et al., 1999) (Zhuang et al., 2010) (Sumardiono et al., 2018). Granulation is a pharmaceutical process of particle design where fine particles are altered to granules or agglomerates (Thapa et al., 2019). High-shear granulation produces strong, dense granules with low tablet tensile strength (Arndt et al., 2018). Artificial rice produced by the granulation method has a breakable texture. However, the extrusion method provides many advantages over the granulation method, including high capacity and high production rate; therefore, it is appropriate for large-scale applications. Several studies have investigated artificial rice made by composite flours from local resources (Putri and Sumardiono, 2020) (Handayani et al., 2016) (Sumardiono et al., 2018). In addition, the use of cereals, tubers (with or without legumes), and fibers as viable sources of functional composite flours continues to increase (Awolu, 2017). However, to the best of our knowledge, artificial rice production made from a combination of sago, arrowroot tuber, and mung bean flours has not yet been evaluated.

This study investigates the effect of composition and extrusion temperature on the carbohydrate, protein, fat, and fiber levels in artificial rice made from different sago, arrowroot tuber, and mung bean flour compositions. Artificial rice's microstructures and thermal stability were also analyzed using scanning electron microscopy (SEM) and differential scanning calorimetry (DSC). The consumer acceptance of the cooked artificial rice (in terms of color, texture, aroma, and taste) was also investigated.

2. Materials and methods

2.1. Materials

Sago, arrowroot tuber, and mung bean flours were the main ingredients for artificial rice production. Flours, salt, glycerol monostearate, and oil were procured from local markets in Semarang, Central Java, Indonesia.

2.2. Artificial rice production

The composite flours (300 g) were mixed with water (50% wt), GMS (2% wt), oil (2% wt), and salt and then steamed for 30 min at 80 °C. The composite flours comprised sago flour (50%–80% wt), arrowroot tuber

flour (10%–40% wt), and mung bean flour (10%–20% wt). The composition of the composite flours was adjusted as described in Table 1. Variations in the composition of these ingredients were made to determine the effect on the nutritional value of artificial rice products since each ingredient has dominant nutritional properties. The pretreated doughs were processed into the extruder (CV Teguh Jaya Teknik Ungaran, Semarang, Indonesia) at various extrusion temperatures (80 °C, 85 °C, and 90 °C). Extrusion temperature can affect the nutritional content of the product because some nutrients are sensitive to heat. Therefore, the effect of variations in extruder temperature on the nutritional content of the artificial rice can be applied in this study. The produced artificial rice was then dried at room temperature for 24 h prior to analysis (Faleh et al., 2017).

2.3. Cooking process

Pour some artificial rice into the rice cooker pot, wash the rice with clean water 2 to 3 times. The pot is then put into the rice cooker. Pour water into the pot of rice until the water level is 2 cm above the rice surface. Turn on the cook button on the rice cooker and wait until the rice is cooked.

2.4. Analytical method

Protein levels of artificial rice were analyzed using Kjeldahl method which consists of three stages, (i) destruction, (ii) distillation, and (iii) titration (SNI 01 2354 4 2006). By this analysis, protein level was determined from the nitrogen level of the artificial rice, utilizing the nitrogen conversion factor 6.25. Fat levels of artificial rice were determined using extraction method (SNI 2891 01 1992). In this analysis, soxhlet and hexane were used as extraction tool and solvent. The level of water was determined using oven at temperature of 105 °C for 3 h (SNI 2891 01 1992). The ash levels of artificial rice were determined using electric furnace at maximum temperature 550 °C until the complete ashing process was obtained (SNI 2891 01 1992). Analysis of carbohydrate content can be determined using the principle of carbohydrate hydrolysis into monosaccharides that can reduce Cu (II) to Cu (I). The excess of Cu (II) can be titrated using iodometry (SNI 2891 01 1992).

The microstructures of artificial rice were observed using scanning electron microscope (SEM – FEI Inspect 50 at 20.0 kV of excitation voltage). A gold (Au) thin layer was applied on the surface of specimen for increasing the quality of image. Further, differential scanning calorimetry analysis of artificial rice was conducted using DSC-60 Plus. The detector, gas flow rate, and cell material used were DSC-60, 10 ml/min, aluminium crimping, respectively.

2.5. Consumer acceptances analysis

The consumer acceptance analysis was carried out to assess the quality of the artificial rice after cooking in terms of texture, color, taste, and aroma using a numerical scale. This test was also determined the preference of cooked artificial rice by consumers. Panelists gave their responses by giving a score of 1 (dislike), 2 (like somewhat), 3 (like), and 4 (like very much). Sixteen people conducted the consumer acceptances analysis (average range age 21–25 years, 10 females, and 6 males) at the Department of Chemical Engineering, Universitas Diponegoro. All panelists involved have agreed to participate in this study by signing the consent form. This study was approved by the ethics committee of the chemical engineering department of Universitas Diponegoro.

3. Result and discussion

3.1. Effect of flour composition on the nutritional value of artificial rice

The nutritional values of artificial rice made from varying flour compositions at different extrusion temperatures are shown in Table 2.

Table 1. Research variables in this study.

| Sample | Sago flour (%w) | Arrowroot tuber flour (%w) | Mung beans flour (%w) | Extrusion temperature (°C) |
|--------|-----------------|----------------------------|-----------------------|----------------------------|
| S1 | 80 | 10 | 10 | 80 |
| S2 | 70 | 10 | 20 | |
| S3 | 70 | 20 | 10 | |
| S4 | 60 | 20 | 20 | |
| S5 | 60 | 30 | 10 | |
| S6 | 50 | 30 | 20 | |
| S7 | 50 | 40 | 10 | |
| S8 | 80 | 10 | 10 | 85 |
| S9 | 70 | 10 | 20 | |
| S10 | 70 | 20 | 10 | |
| S11 | 60 | 20 | 20 | |
| S12 | 60 | 30 | 10 | |
| S13 | 50 | 30 | 20 | |
| S14 | 50 | 40 | 10 | |
| S15 | 80 | 10 | 10 | 90 |
| S16 | 70 | 10 | 20 | |
| S17 | 70 | 20 | 10 | |
| S18 | 60 | 20 | 20 | |
| S19 | 60 | 30 | 10 | |
| S20 | 50 | 30 | 20 | |
| S21 | 50 | 40 | 10 | |

The nutritional values evaluated were carbohydrates (%), protein (%), fat (%), and fiber (%).

3.1.1. Carbohydrates

Artificial rice S19 (60:30:10; 90 °C) was found to have the highest carbohydrate content among all artificial rice (84.67%), whereas artificial rice S2 (70:10:20; 80 °C) was found to have the lowest carbohydrate content (77.34%) (Table 2). The carbohydrate level of the artificial rice is influenced by the carbohydrate level of each raw material, and sago and arrowroot tubers have higher carbohydrate levels than mung beans (Abbas et al., 2010) (Yenrina et al., 2015). The formulation, which uses a higher composition of sago and arrowroot tuber flour than mung bean, will produce artificial rice with high carbohydrate content. The carbohydrate content of our artificial rice was higher than that of commercial rice (77.1%); thus, it can be used as an alternative staple food to provide daily energy needs.

Furthermore, the carbohydrate content of the artificial rice consists of available (amylopectin) and non-available (amylose) carbohydrates. The higher level of amylose might be related to the low glycemic index (GI) since amylose cannot be digested by enzymes and cannot be absorbed as glucose by the intestine. In this study, the arrowroot tuber flour was found to have a lower GI than that of the other flours (Lestari et al., 2017); therefore, the use of arrowroot tuber flour as one of the main ingredients could provide the added value of the prevention against type 2 diabetes mellitus.

3.1.2. Protein

Artificial rice S6 (50:30:20; 80 °C) was found to have the highest level of protein (6.42%), whereas rice S21 (50:40:10; 90 °C) had the lowest protein level (2.39%) (Table 2). The amount of mung bean flour influences the protein content of the artificial rice used because it has a high protein level (1.8 g/100 g) compared with sago flour (0.2 g/100 g) and arrowroot tuber flour (1 g/100 g). However, the protein content of this artificial rice was lower than that of commercial rice, possibly owing to the lower use of mung bean flour. The consumption of artificial rice may still help meet the body's protein needs since people usually consume other protein sources, such as meat, fish, and eggs. Protein can stimulate insulin secretion so that blood glucose is controlled; hence, it can affect the GI value of artificial rice (Layman and Baum, 2004). Artificial rice that contains high protein levels has low glycemic activity since it can inhibit the glucose absorption process in the small intestine.

3.1.3. Fat

Artificial rice S19 (60:30:10; 90 °C) was found to have the highest (0.58%) level of fat among the artificial rice, and S6 (50:30:20; 80 °C) had the lowest (0.15%) level of fat (Table 2). Mung bean flour contains high-fat content; therefore, the fat content of the artificial rice was influenced by the mung bean flour content. The total recommended fat intake is 15%–35% of the daily diet (Elmadfa and Kornsteiner, 2009). However, the artificial rice produced in the present study had a lower fat level than commercial rice, possibly owing to the common use of mung bean flour. Besides, the fat in mung beans is an unsaturated fatty acid suitable for overweight people and those who suffer from heart disease.

Fat is a macronutrient that has essential functions as a source of energy and acts as a solvent for vitamins A, D, E, and K. However, high fat levels can inhibit the digestive process. Foods that contain high levels of fat tend to have low GI values. However, excessive fat consumption can initiate the increase of cholesterol levels and is thus harmful to the body. Therefore, the low level of fat in our artificial rice can be beneficial for the human body.

Table 2. Nutritional values of the artificial rice.

| Sample | Carbohydrate (%) | Fat (%) | Protein (%) | Water (%) | Fiber (%) |
|--------|--------------------------|---------------------------|---------------------------|---------------------------|---------------------------|
| S1 | 80.05 ± 0.3 ^a | 0.45 ± 0.001 ^a | 4.29 ± 0.004 ^a | 12.23 ± 0.04 ^a | 1.05 ± 0.002 ^a |
| S2 | 77.34 ± 0.7 ^b | 0.52 ± 0.003 ^b | 6.25 ± 0.005 ^b | 13.22 ± 0.02 ^a | 1.54 ± 0.004 ^a |
| S3 | 80.76 ± 0.1 ^a | 0.42 ± 0.005 ^a | 3.67 ± 0.006 ^c | 12.31 ± 0.07 ^a | 0.95 ± 0.001 ^a |
| S4 | 79.00 ± 0.4 ^c | 0.55 ± 0.002 ^b | 5.60 ± 0.003 ^a | 13.96 ± 0.02 ^a | 1.62 ± 0.005 ^a |
| S5 | 80.50 ± 0.3 ^a | 0.42 ± 0.001 ^a | 3.85 ± 0.008 ^c | 11.69 ± 0.01 ^a | 1.02 ± 0.002 ^a |
| S6 | 77.64 ± 0.8 ^b | 0.58 ± 0.003 ^b | 6.42 ± 0.007 ^b | 12.33 ± 0.05 ^a | 1.53 ± 0.006 ^a |
| S7 | 81.32 ± 0.2 ^a | 0.44 ± 0.004 ^a | 3.61 ± 0.004 ^c | 11.21 ± 0.06 ^a | 1.02 ± 0.003 ^a |
| S8 | 81.96 ± 0.3 ^a | 0.33 ± 0.005 ^c | 2.92 ± 0.005 ^d | 11.11 ± 0.07 ^a | 1.32 ± 0.005 ^a |
| S9 | 79.17 ± 0.7 ^a | 0.46 ± 0.006 ^a | 5.14 ± 0.008 ^b | 11.26 ± 0.03 ^a | 1.77 ± 0.007 ^b |
| S10 | 82.01 ± 0.5 ^d | 0.33 ± 0.002 ^c | 2.76 ± 0.003 ^d | 11.07 ± 0.01 ^a | 1.08 ± 0.003 ^a |
| S11 | 80.22 ± 0.2 ^a | 0.46 ± 0.001 ^a | 4.65 ± 0.005 ^a | 11.22 ± 0.07 ^a | 1.80 ± 0.006 ^b |
| S12 | 82.06 ± 0.7 ^d | 0.33 ± 0.003 ^c | 3.02 ± 0.007 ^c | 11.03 ± 0.04 ^a | 1.11 ± 0.002 ^a |
| S13 | 80.27 ± 0.4 ^a | 0.46 ± 0.005 ^a | 5.14 ± 0.004 ^b | 11.18 ± 0.03 ^a | 1.83 ± 0.005 ^b |
| S14 | 82.11 ± 0.3 ^d | 0.33 ± 0.004 ^c | 2.56 ± 0.006 ^d | 10.99 ± 0.06 ^b | 1.14 ± 0.004 ^a |
| S15 | 83.46 ± 0.6 ^d | 0.21 ± 0.001 ^d | 2.75 ± 0.003 ^d | 9.34 ± 0.02 ^b | 1.63 ± 0.003 ^b |
| S16 | 80.70 ± 0.2 ^a | 0.42 ± 0.003 ^a | 4.32 ± 0.007 ^a | 11.04 ± 0.05 ^a | 1.96 ± 0.007 ^b |
| S17 | 84.01 ± 0.1 ^d | 0.25 ± 0.002 ^d | 2.43 ± 0.006 ^d | 8.98 ± 0.03 ^b | 1.32 ± 0.004 ^a |
| S18 | 80.66 ± 0.4 ^a | 0.26 ± 0.006 ^d | 3.84 ± 0.003 ^c | 10.26 ± 0.06 ^b | 1.95 ± 0.006 ^b |
| S19 | 84.67 ± 0.2 ^d | 0.15 ± 0.005 ^d | 2.68 ± 0.005 ^d | 10.21 ± 0.04 ^b | 1.24 ± 0.001 ^a |
| S20 | 81.22 ± 0.6 ^a | 0.28 ± 0.002 ^d | 4.21 ± 0.007 ^a | 10.15 ± 0.07 ^b | 2.12 ± 0.004 ^b |
| S21 | 84.54 ± 0.2 ^d | 0.18 ± 0.004 ^d | 2.39 ± 0.008 ^d | 9.22 ± 0.02 ^b | 1.44 ± 0.003 ^a |

Values are mean ± standard deviation of three replicates. ^{a–b}Samples represented with different letters are significantly different (P < 0.05).

Table 3. Gelatinization temperatures of flours used to make artificial rice.

| Raw materials | Gelatinization temperature (°C) |
|------------------------|---------------------------------|
| Arrowroot tubers flour | 85.5 |
| Mung beans flour | 70.0 |
| Sago flour | 84.0 |

3.1.4. Moisture content

Artificial rice S4 (60:20:20; 80 °C) had the highest (13.96%) moisture content, whereas S17 (70:20:10; 90 °C) had the lowest (8.98%) (Table 2). The moisture content of artificial rice was found to be below the maximum required level (<14% w/w); hence, mold growth would be inhibited. High water content activity influences the spoilage development of food products (Abbas et al., 2009).

3.1.5. Fiber

Artificial rice S20 (50:30:20; 90 °C) had the highest (2.05%) fiber content, whereas S1 (80:10:10; 80 °C) had the lowest (1.09%) (Table 2). The primary source of fiber in the artificial rice produced in this study was mung beans. Therefore, the fiber level of the artificial rice was influenced by the mung bean flour content. Fiber is closely related to the GI value of foods and contributes to low GI values (Trinidad et al., 2010). In its complete form, fiber can act as a physical barrier that inhibits food transport and enzyme activity, thus extending the digestive process.

3.2. Effect of extrusion temperature on the nutritional value of artificial rice

Food extrusion technology forces soft ingredients through a barrel and passes them through a die that is designed to produce the desired shape (Rossen and Miller, 1973). The gelatinization process is obtained in the extrusion process due to the simultaneous heat and water penetration with stirring, kneading, compression, and shear stress (Moscicki et al., 2013). The extrusion temperature is strongly influenced by the gelatinization temperature of each flour (Table 3). The heat and water used in the gelatinization process will lead to the formation of swollen granules so that amylase can diffuse out of the granules (Harper and Clark, 1979). The water absorption in the amorphous area will also initiate the lost crystalline structural stability of starch granules (Ratnayake and Jackson, 2006).

The effects of the different experimental extrusion temperatures (80 °C, 85 °C, and 90 °C) on the carbohydrate, protein, fat, and fiber contents of the artificial rice are shown in Figure 1. The experiment was conducted in the same formulation of flour. Figure 1(a) shows that higher temperatures did not significantly alter the carbohydrate content. The highest carbohydrate content (81.22%) and the lowest (77.64%) were obtained at 90 °C and 80 °C, respectively.

Figure 1(a) also shows that the lowest protein content (4.21%) was obtained at 90 °C. The higher temperature used would induce the denaturation of proteins in artificial rice (Matsuura et al., 2015). Higher temperatures and pH will initiate structural changes in proteins (Lam and Nickerson, 2015). The denaturation process results in partial or total modification or alteration of proteins' secondary, tertiary, and quaternary molecular structure. Temperature is the main factor that can influence food processing, thus determining food quality.

The effect of extrusion temperature on fat and fiber content is shown in Figure 1(b). The lowest fat content (0.28%) was obtained at 90 °C. A previous study reported that food processing could reduce the quality and level of fats in food (Augustin et al., 2016). The degree of fat loss varies depending on the temperature and duration of heat exposure. Fat is susceptible to heat and melts and evaporates during the cooking process.

Figure 1(b) shows that the highest (2.12%) and lowest (1.53%) fiber contents were obtained at 90 °C and 80 °C, respectively. It also indicates that the fat and fiber levels increased because of high temperatures, which decrease the water content.

3.3. Morphology of artificial rice

Figure 2 shows the morphological structure of the artificial rice made from 50% sago flour, 30% arrowroot tuber flour, and 20% mung bean flour at three different temperatures (80 °C, 85 °C, and 90 °C). Figure 2(a1) and 2(a2) show that some granules were in complete form because the starch had not disintegrated, whereas others were defective because of gelatinization and retrogradation under magnifications 500 x and 5,000 x, respectively. As a result, some granules appeared individually, whereas others were stuck together. The fragility of artificial rice may have caused this occurrence. In artificial rice production, absorbed water forms swollen granules, and the gelatinization process breaks the intramolecular hydrogen bonds (Alcazar-Alay and Meireles, 2015).

Figure 2(b1) and 2(b2) show the artificial rice produced at 85 °C under magnifications 500 x and 5,000 x, respectively. The SEM images indicate that most granules stick together as they break. Figure 2(c1) and 2(c2) show that almost all granules stick to each other at a production temperature of 90 °C under magnifications 500 x and 5,000 x, respectively. The images also show that many granules break and form strong bonds with others. In addition, the higher extrusion temperature would increase the number of bonds, thus increasing the hardness of artificial rice.

Figure 3 shows the microstructures of artificial rice S11, S12, and S13 at an extrusion temperature of 85 °C under magnifications 500 x and 5,000 x. Figure 3(a1), 3(a2), 3(c1), and 3(c2) show that the number of swollen granules increased and began to stick to each other. However, Figure 3(b1) and 3(b2) show the swollen granules that were not defective and do not interact. These two different properties reflect the differences in the fiber and carbohydrate content of each artificial rice. Water absorption was influenced by the presence of fiber (Dhingra et al., 2012),

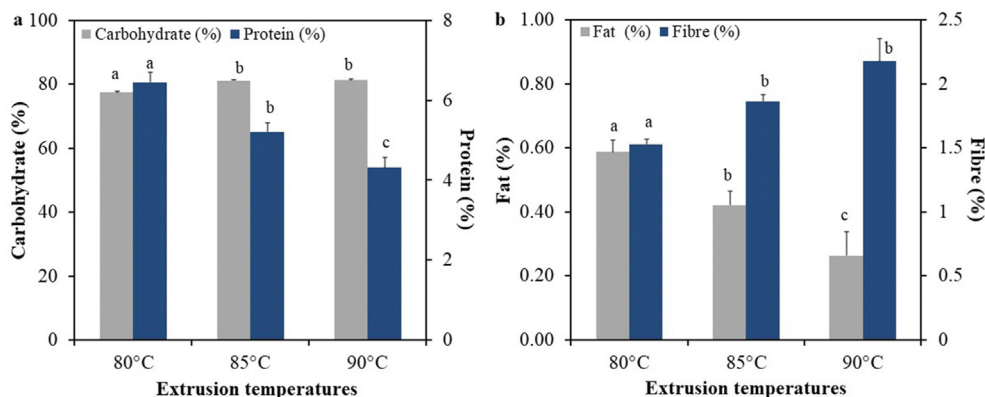


Figure 1. Effect of extrusion temperature on the level of (a) carbohydrate and protein and (b) fat and fiber. Values are mean \pm standard deviation of three replicates. ^a ^bSamples represented with different letters are significantly different ($P < 0.05$).

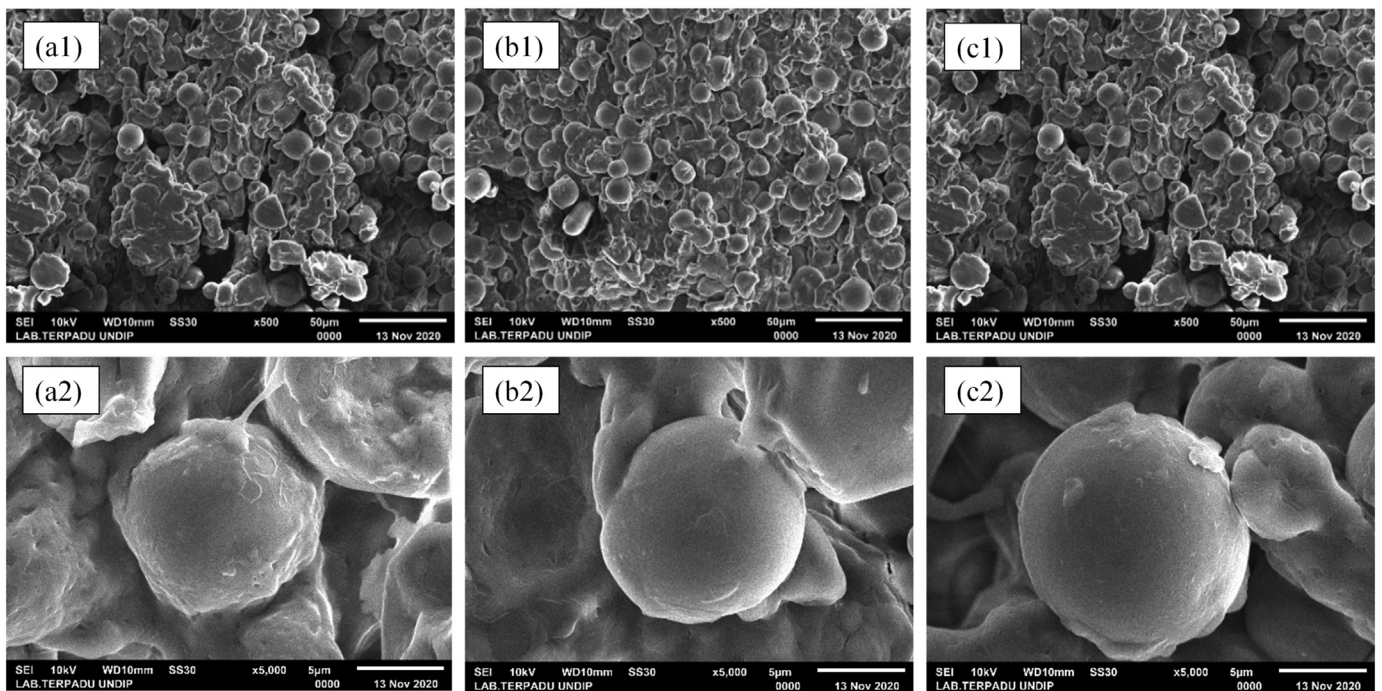


Figure 2. The morphological structure of artificial rice produced from 50% sago flour, 30% arrowroot tuber flour, and 20% mung bean flour at varying temperatures (a) 80 °C, (b) 85 °C, and (c) 90 °C under (1) 500 x and (2) 5,000 x magnifications.

whereby low levels of fiber induced a low amount of water to enter the granules. Therefore, the granules did not swell well and appear incompletely formed.

3.4. Organoleptic analysis of artificial rice

Organoleptic analysis was conducted to determine the quality of the artificial rice produced by this study. We obtained 60 responses from 15

respondents. Artificial rice S8 (80:10:10; 85 °C), S9 (70:10:20; 85 °C), S10 (70:20:10; 85 °C), S11 (60:20:20; 85 °C), S12 (60:30:10; 85 °C), S13 (50:30:20; 85 °C), and S14 (50:40:10; 85 °C) were cooked and used as assessment objects. Respondents provided scores of 1 (dislike), 2 (slightly like), 3 (like), and 4 (like very much). Figure 4 shows the appearance of raw (a) and (b) cooked artificial rice. The color of S12(a) and S13(a) are lighter than the others so that it is preferred by consumers. Figure 4(b) also indicates that the texture of cooked rice S12(b) and S13(b) is fluffier

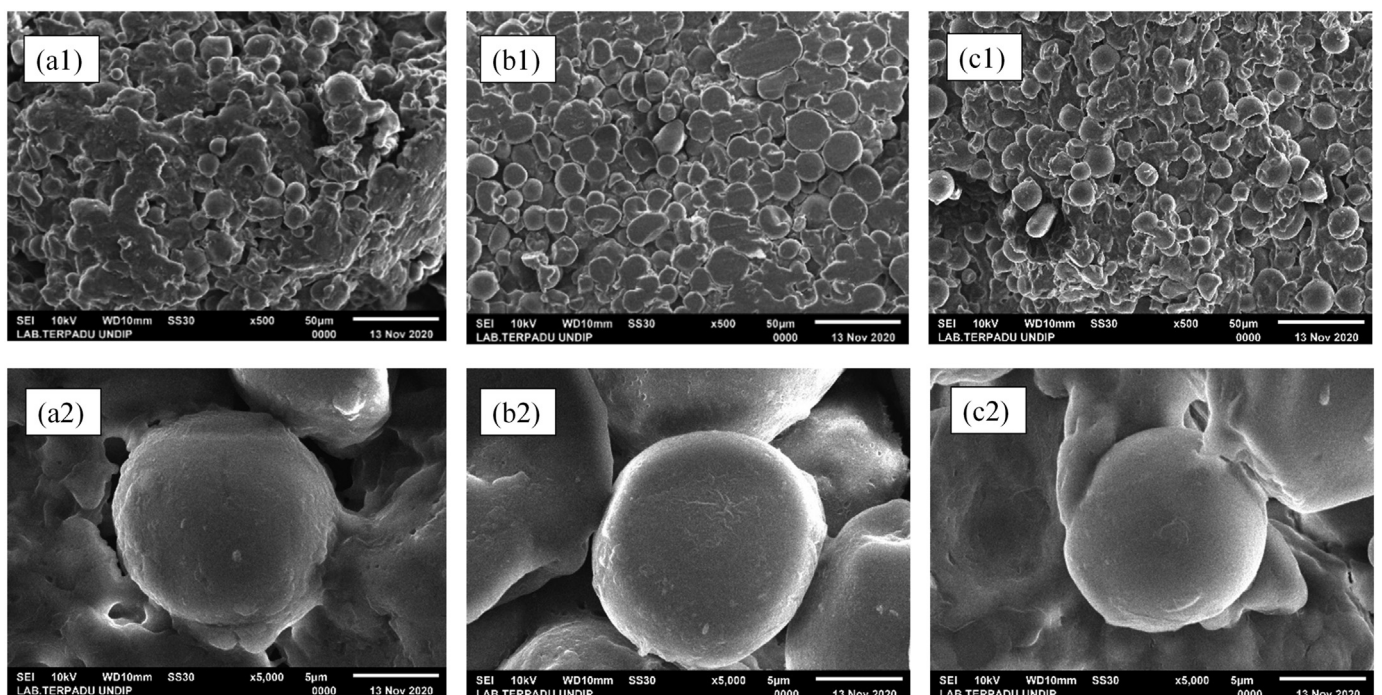


Figure 3. The morphological structure of artificial rice (a) S11, (b) S12, and (c) S13 under (1) 500 x and (2) 5,000 x magnifications at extrusion temperatures of 85 °C.



Figure 4. The appearance of (a) raw artificial rice and (b) cooked artificial rice S8, S9, S10, S11, S12, S13, and S14.

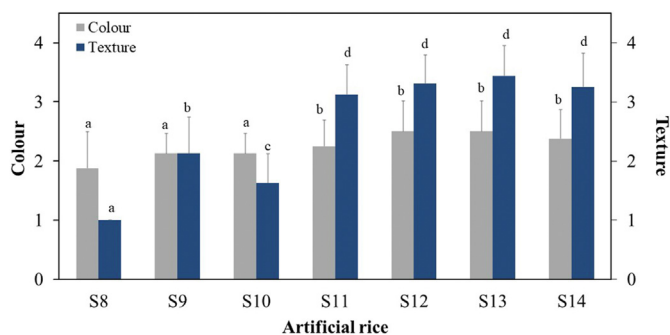


Figure 5. Respondents' assessment of artificial rice in terms of color and texture. Values are mean \pm standard deviation of three replicates. ^{a-b}Samples represented with different letters are significantly different ($P < 0.05$).

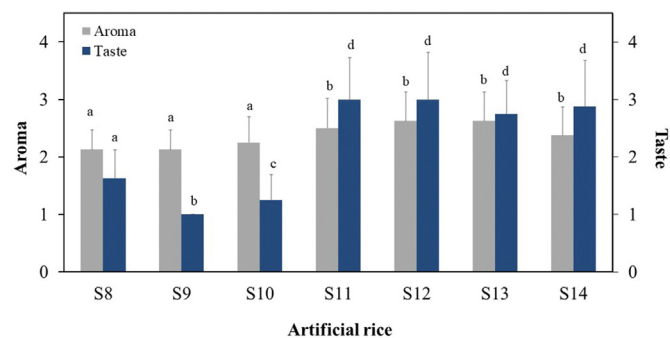


Figure 6. Respondents' assessment of artificial rice in terms of aroma and taste. Values are mean \pm standard deviation of three replicates. ^{a-b}Samples represented with different letters are significantly different ($P < 0.05$).

and softer than other formulas, thus it is more desirable. Moreover, the respondents' assessments of the cooked artificial rice in terms of color-texture and aroma-taste are represented in Figures 5 and 6.

3.5. Features of cooked artificial rice

3.5.1. Color

Color is one of the main factors determining the first impression and consumer acceptance (Wu and Sun, 2013). Nutritious food, is delicious and has a perfect texture, will not be eaten if it has an unsightly color. The mean scores for the color of artificial rice S8, S9, S10, S11, S12, S13, and S14 were 1.88, 2.13, 2.13, 2.25, 2.5, 2.38, and 2.38, respectively (Figure 5). Rice S8 (80:10:10; 85 °C) had the lowest color value, whereas S12 (60:30:10; 85 °C) had the highest color value. Respondents were able to accept the color of artificial rice S13 (50:30:20; 85 °C) and S14 (50:40:10; 85 °C). The product had a brownish white color that was probably caused by sago flour, which underwent an enzymatic browning process. Enzymatic browning is an oxidation reaction that involves polyphenol enzymes. Polyphenols were oxidized to dipolycarbonyl or polycarbonyl compounds, which create a brown or reddish color. This coloration can occur when the sago starch is extracted too late. This can be seen in S8, which had the highest proportion of sago flour and had the darkest color. The dark color might also be caused by a non-enzymatic brownish reaction (Maillard reaction) due to the heating process at high temperatures, such as roasting, frying, roasting, and other cooking processes (Yu et al., 2018). In this study, the heating process was conducted via steaming and extraction.

3.5.2. Texture

Texture is another sensory property that can influence picky eating behavior (Werthmann et al., 2015). The mean values for the texture

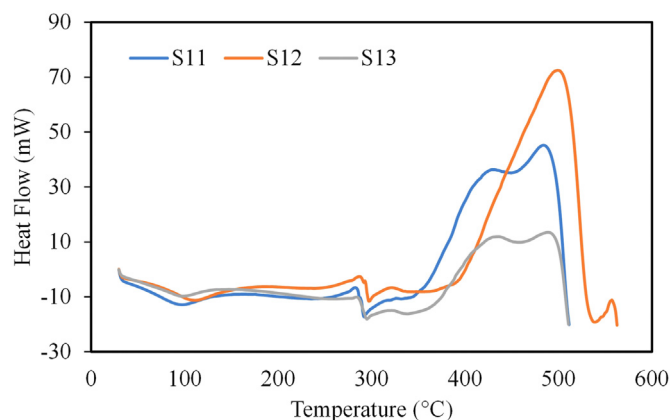


Figure 7. Differential scanning calorimetry (DSC) thermogram of artificial rice S11, S12, and S13 at an extrusion temperature of 80 °C.

parameters of artificial rice S8, S9, S10, S11, S12, S13, and S14 were 1.00, 2.13, 1.63, 3.13, 3.38, 3.63, and 3.25, respectively (Figure 5) Rice S8 (80:10:10; 85 °C) had the lowest texture value, whereas rice S13 (50:30:20; 85 °C) had the highest. The results showed that cooked artificial rice had a chewy texture, was not too sticky, and was fluffy (after cooling), similar to native rice. However, the artificial rice with high proportions of sago starch had a slightly sticky texture, possibly owing to the amylopectin content in the flour, which determined the nutritional content and physical structure of the rice when cooked. The cooked rice will be soft if the amylopectin content of the ingredient is higher than the amylose content. Ingredients with high amylopectin contents will produce sticky, shiny rice that remains lumpy after cooling.

3.5.3. Aroma

Aroma is an important parameter that determines consumer acceptance. Foodstuffs that have an overpowering aroma tend to be disliked for consumption. The aroma generated by artificial rice was influenced by several factors, including residence time, extrusion temperature, pressure, and diffusivity of volatile materials (Korompis et al., 2016). The average values for the aroma parameter of artificial rice S8, S9, S10, S11, S12, S13, and S14 were 2.13, 2.13, 2.38, 2.5, 2.63, 2.63, and 2.38, respectively (Figure 6). The highest values for the aroma parameter were obtained by rice S12 (60:30:10; 85 °C) and S13 (50:30:20; 85 °C), whereas the lowest values were obtained by S8 (80:10:10; 85 °C) and S9 (70:10:20; 85 °C). The results showed that the aroma of the artificial rice was slightly musty. The aroma generated from artificial rice was influenced by the raw material composition and the processing. The formation of a sour and musty odor could be caused by microorganisms, browning reactions, and starch hydrolysis. Furthermore, cooking oil needs to be controlled since it can affect the aroma and taste of artificial rice. Poorly stored cooking oil could initiate the breakdown of triglyceride bonds into glycerol and FFA and thereby influence the quality of oil (Mendez and Falque, 2007).

3.5.4. Taste/flavor

The results showed that the average taste values for artificial rice S8, S9, S10, S11, S12, S13, and S14 were 1.63, 1.00, 1.25, 3.00, 3.00, 2.75, and 2.88, respectively (Figure 6). S11 (60:20:20; 85 °C) and S12 (60:30:10; 85 °C) had the highest values, whereas S9 (70:10:20; 85 °C) had the lowest value. Overall, the consumers accepted the taste of the cooked artificial rice. Artificial rice made from a high composition of arrowroot tuber flour was reported to taste similar to native rice. However, artificial rice with a high composition of sago flour had a bitter and slightly sour taste. In addition, sago tends to be tasteless, but improper storage and quality control could induce an unpleasant taste (Sumardiono et al., 2021a) (Sumardiono et al., 2021b). Humid storage conditions cause the growth of molds and yeasts on the surface of the rice,

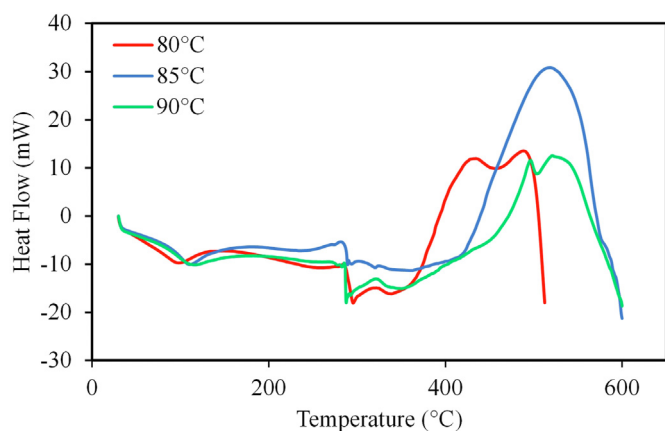


Figure 8. Differential scanning calorimetry (DSC) thermogram of artificial rice S13 at varying extrusion temperatures of 80 °C, 85 °C, and 90 °C.

which initiates a sour and musty odor. Good-quality ingredients are required to produce a pleasant taste in artificial rice.

3.6. DSC analysis of artificial rice

The DSC profiles of artificial rice S11 (60:20:20; 85 °C), S12 (60:30:10; 85 °C), and S13 (50:30:20; 85 °C) are shown in Figure 7. All investigated rice had multiple peaks due to the use of composite ingredients. At a temperature of around 100 °C, endothermic peaks indicated that all investigated rice changed in physical structure. Figure 6 also depicts the exothermic peaks, which indicated that all investigated rice experienced a change in physical and chemical properties at a temperature of around 300 °C. Furthermore, the differences in thermal profiles began to occur at temperatures over 400 °C. Further chemical changes were shown by S11 (60:20:20; 85 °C) and S13 (50:30:20; 85 °C) at temperatures around 400 °C, and they completely degraded at 480 °C. However, artificial rice S12 (60:30:10; 85 °C) underwent a complete chemical change and degraded at 500 °C, possibly because of the higher level of protein in rice S12 (60:30:10; 85 °C). A previous study reported that high use of peanut protein isolate could shift thermal properties (Colombo et al., 2010).

Figure 8 represents the DSC profiles of artificial rice S13(50:30:20; 85 °C) produced by varying extrusion temperatures (80 °C, 85 °C, and 90 °C). Generally, both samples had a similar profile at 100 °C and 300 °C. However, differences in the DSC profiles were observed at a temperature of around 400 °C. The higher extrusion temperature shifted the exothermic peak into a higher temperature. The chemical changes of the artificial rice produced by the extrusion temperatures of 80 °C and 90 °C began at 420 °C and 490 °C, respectively, but the rice completely degraded at 485 °C and 520 °C, respectively. However, the artificial rice produced by extrusion at 85 °C had a complete chemical change at a temperature of 520 °C.

4. Conclusion

Based on the proximate analysis of various compositions, the best artificial rice produced was S13, consisting of 50% sago flour, 30% arrowroot tuber flour, and 20% mung bean flour. This formulation's water content, carbohydrate, protein, fat, and fiber content were 11.18%, 80.27%, 5.14%, 0.46%, and 5.14%, respectively. Based on the effect of temperature on the nutritional content of artificial rice, the levels of protein, fat, and water content decreased with increasing temperature, whereas the carbohydrate and crude fiber levels increased. Therefore, the optimum temperature for the production of artificial rice is 85 °C. The DSC profiles showed that artificial rice S11 (60:20:20; 85 °C), S12 (60:30:10; 85 °C), and S13 (50:30:20; 85 °C) began undergoing physical changes at approximately 100 °C. In this study, artificial rice S13 was reported to have a texture, aroma, taste, and appearance that were

similar to those of native rice, and our consumers accepted it as a substitute for rice. Furthermore, the color, texture, aroma, and taste of the cooked artificial rice were accepted by our consumers.

Declarations

Author contribution statement

Siswo Sumardiono: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Bakti Jos: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

Muhammad Fariz Zakly Antoni, Yusrina Nadila: Performed the experiments; Analyzed and interpreted the data.

Noer Abyor Handayani: Analyzed and interpreted the data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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