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Physico-Chemical Characteristics of Novel Analog Rice from Fermented Sorghum Flour by *Rhizopus oligosporus* and Soybean Flour

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Abstract

The need for food in the world is currently increasing, one of high consumption is rice. Analog rice is one of the products for rice substitute consumption to meet staple food with better nutritional value. In this research, the production of analog rice was made from fermented sorghum using *Rhizopus oligosporus* which has been studied previously with the addition of soybean flour fortification. Raw materials of sorghum grain were fermented using *Rhizopus oligosporus* to reduce tannin levels of sorghum and the addition of fortified soybean flour aims to increase the nutrition of analog rice. Analog rice production is carried out using the extrusion method with fermented sorghum flour with fortified soybean flour in a ratio of 0 to 50%. Nutritional value of analog rice (carbohydrates, protein, fat, fiber, minerals, and water), morphology, water adsorption index (WAI), water solubility index (WSI), hydrophilicity, and consumer acceptance were characterized. The best nutritional of analog rice produced was obtained from the combination of 50% sorghum (red or white sorghum) and 50% soybean flour, which contained carbohydrates, protein, fat, and fiber of 58.29%, 17.07%, 14.47%, and 7.43% respectively. The increasing portion fortified of soybean flour was reduced the WAI and increased the density of the analog rice structure. These characteristics are friendly to diabetic patients since they

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are rich in carbohydrates, protein, and fiber. On the other hand, this analog rice has the potential to be consumed as a main food ingredient to replace paddy rice and develop to staple food. Moreover, the insignificant effect of the WSI value and hydrophilicity of the analog rice were observed. However, adding soybean flour as a substitute for analog rice was less attractive to consumers than analog rice without substitutes.

Introduction

Rice is one of the staple foods in most Asian countries. Rice is produced from milled paddy and cooked by boiling or steaming commonly. In most cases, rice is farmed in rice fields with specific soil characteristics in tropical and sub-tropical countries.[1] Several nations, particularly developing countries, are suffering from a food crisis, so they require supplies of other food sources.[2] Several countries have issued policies to bolster national food security.[3] The agricultural sector needs to be improved to meet food security with high yields and more efficient methods.[4] On the other hand, excessive rice consumption has been reported to negatively impact human health, such as causing obesity and diabetes.[5] Hence, food alternatives with similar ingredients to paddy rice for human consumption are needed.[6]

The development of analog rice using various methods have attracted more attention from researchers. Analog rice is one of the innovations to solve the food crisis problem. It is produced from non-paddy rice plants and utilizes local plants with carbohydrates close to rice from paddy, even with higher nutrient content.[7,8] Several researchers have produced analog rice from various raw materials, such as cassava, sago, corn, sorghum, and other raw materials with good nutritional and physical appearance.[9,10] Purwaningsih *et al*.[10] reported that they have produced rice with *Gracillaria sp* materials containing 77.7-80.3% carbohydrates, 2.7-5.9% protein, and 0.3-3.7% fat. Wahjuningsih *et al*.[11] prepared analog rice from a mixture of mocaf flour, arrowroot, and red bean flour containing protein, fat, and carbohydrates of 6.17%, 1.31%, and 89.88%, respectively.

Fermented sorghum (*Sorghum bicolor* L. Moench) flour and soybean flour were used as composite raw materials of analog rice. Sorghum is one of the cereals that can grow in soils with poor nutrients.[11] Sorghum has 32 species and is extensively grown in tropical and sub-tropical countries, especially in Australia-Asia and Southeast Pacific.[12] Sorghum has a reasonably good nutritional value, including carbohydrate, protein, ash, fat, and fiber with the concentration of 55.2–72.2%, 8.6–18.9%, 1.1–2.4%, 1.7–4.9%, and 9.3–25.2% respectively.[13] However, untreated sorghum seeds have a relatively high concentration of condensed tannins, i.e., up to 10.66%.[14] High condensed tannins reduce consumer acceptability to sorghum grains due to their tart taste and anti-nutrient nature. The maximum concentration of tannin allowed for food products, as suggested by the Food and Agriculture Organization (FAO), is only 0.5%.[15] According to previous studies, soaking with dilute alkali and fermentation with *Rhizopus oligosporus* could reduce tannins up to 0.25%, which met the established FAO standards.[11] Meanwhile, the fortification of soybean flour could enhance protein in analog rice. Soybean itself is known to have a fairly good nutritional value, with 35% carbohydrates and protein of 40% and 37%, respectively.[16] So the production of analog rice using fermented sorghum as raw material with fortified soybean flour produces rice with good nutritional value and can be used as an alternative food.

Analog rice can be produced using single or composite raw materials by granulation or extrusion methods.[17] In general, the granulation method compacts the fine particles of flour into small grains resembling rice. In the extrusion method, the fine particles of the flour compacted under high pressure and temperature of drying to form solid grains such as rice.[18] Analog rice can be produced by adding other raw materials or composite flour to increase the nutritional should meet consumer acceptance.[19] However, the characteristics and sensory test evaluation results of the product must be acceptable to consumers.[20] Thus, composite flour as the raw material for analog production is potentially developed in the future.

One potential combination is modified *R. oligosporus* sorghum seeds as raw material with soybean flour as an additive, which has not yet been evaluated. This study aimed to evaluate the effect of the composition of fermented sorghum flour and soybean flour, particularly in physico-chemical characteristics and consumer acceptance rate. It is hoped that the results of this research can become an alternative food with high nutrition and as a solution to food security.

Materials and Methods

Materials

Two varieties of sorghum, i.e., red and white sorghum, were used and purchased from local farmers (Bantul, Indonesia). Soybean flour was purchased from Prime Dfood, (Bandung, Indonesia). The nutrition of raw materials were depicted in Table 1. The *R. oligosporus* used for fermentation was purchased from PT. Aneka Fermentasi Industri, (Bandung, Indonesia), with an activity of 1.0×102 CFU/g. Glycerol monostearate purity of 95% was obtained from Rikevita Fine Chemical & Food Industry Co. (Johor, Malaysia). NaOH purity of 99% as a solvent during immersion was obtained from Merck (Darmstadt, Germany). Olive oil purity of 99% was purchased from Bertolli (Lucca, Italy). Salt with a purity of 95% was acquired from Revina (Sidoarjo, Indonesia).

Table 1: Proximate analysis of flour raw materials

Raw Materials	Parameters					
	Carbohydrate (%)	Protein (%)	Fat (%)	Crude fiber (%)	Moisture (%)	Minerals (%)
Red Sorghum	76.63 ± 0.28	8.26 ± 0.05	4.33 ± 0.18	5.60 ± 0.31	9.28 ± 0.04	1.49 ± 0.09
White Sorghum	74.59 ± 0.07	7.34 ± 0.16	2.85 ± 0.12	6.34 ± 0.45	13.70 ± 0.04	1.50 ± 0.26
Soybean	37.38 ± 0.11	28.80 ± 0.11	20.07 ± 0.02	8.52 ± 0.72	9.48 ± 0.06	4.26 ± 0.01

Pretreatment and Fermentation Method

Sorghum pretreatment process refers to Bahlawan *et al*.[11] The sorghum seeds were first washed with distilled water. Sorghum seeds were subsequently soaked in 0.3% NaOH solutions for 10 h until the solvent level was above the surface of the sorghum seeds. Afterward, the sorghum seeds were washed with distilled water and dried in an oven (Memmert 55, Schwabach, Germany) at 55°C for 2 h or until dry. The dried grains were then milled with a grinder (Fomac, Jakarta, Indonesia) and sieved with a test sieve (KZM, Purwakarta, Indonesia) to a 100-mesh size. Before fermentation, sorghum flour was sterilized using an autoclave (FLS-1000, Tokyo, Japan) at 121°C for 15 min. The pH of sorghum flour was adjusted using vinegar (PT Heinz ABC Indonesia, Jakarta, Indonesia) to 5.5. The next step was the solid-state anaerobic fermentation process of the flour by adding 7.5% (w/w) *R. oligosporus* at 30°C for 48 h. The fermented sorghum flour was dried again in an oven at 55°C for 2 h and stored in a sealed container, which then was used for analog rice production. The process of soaking for 1:1 (wt of grain: wt of solvent).

Analog Rice Production

Fermented sorghum flour and soybean flour were mixed with a mixer (Philips EHM 9595, Batam, Indonesia) according to the variables to produce composite flour, as described in Table 2. Mixed rice ingredients for analog rice production were referred to Sumardiono *et al*.[9] Blended flour of 300 g that had been mixed with glycerol monostearate (Rikevita SDN, Johor, Malaysia) (2% wt), olive oil (2% wt), and 5 g of salt was subsequently steamed for 40 min at 80°C. Variations in analog rice composition aimed to determine each analog rice's nutritional value and morphology as well as the effect of adding soybean flour. Afterward, the raw materials were processed using an extruder tool (CV Maksindo, Malang, Indonesia) and dried in an oven at 70°C for 3 h. The analog rice was then stored in a dry room for 24 h at room temperature for further analysis.

Table 2: Research variable in this study.

Sample	Fermented red sorghum flour (%wt)	Fermented white sorghum flour (%wt)	Soybean Flour (%wt)
1	100	-	-
2	90	-	10
3	80	-	20
4	70	-	30
5	60	-	40
6	50	-	50
7	-	100	-
8	-	90	10
9	-	80	20
10	-	70	30
11	-	60	40
12	-	50	50

Nutritional Analysis

The principle of the hydrolysis of carbohydrates into monosaccharides was applied to the carbohydrate analysis method of analog rice (AOAC-955.13).[21] Protein level was analyzed with the Kjeldahl Method utilizing a nitrogen conversion factor of 6.25 and three phases of analysis destruction, distillation, and titration (AOAC-2001.11).[22] The Soxhlet Method was used to calculate the level of fat (AOAC-2003.06).[22] Hexane solvent will be used to extract fat for this assay. Gravimetric analysis was used to examine crude fiber (AOAC-978.10).[22] Using this procedure, the fiber remnant will be heated to a temperature of 550°C in the furnace until it turns to ash. Moisture content was determined using the Thermogravimetric method (AOAC-934.01) by heating the sample at 100°C for three hours.22 While the minerals level method was referred to (AOAC-985.30).[22]

Energy

The energy calculation process was referred to Schakel *et al.*[23] Each macronutrient produces a different calorific value, i.e., 4 kcal/g protein, 9 kcal/g fat, and 4 kcal/g carbohydrates. The nutritional value of each analog rice per 50 g serving was calculated for its calorific value and calculated based on the calorific value of macronutrients by following the equation below:

Total calories (g) ={(% protein x 4kcal)+(%fat x 9 kcal)+ (%carbohydrate x 4kcal)} ...(1)

Scanning Electron Microscopy (SEM)

To analyze the microstructure of analog rice, a Scanning Electron Microscopy (SEM) analysis is conducted using the JSM-6510LA (JEOL Ltd, Japan). A thin gold (Au) layer was applied onto the surface of the analog rice to enhance the quality of the images. Starch was affixed onto a sample holder (approximately 10 mm, aluminum stub) using adhesive tape on both sides and subsequently coated with a mixture of gold-palladium (60:40). An acceleration voltage of 10 kV was utilized for the micrography process.

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

The water absorption index (WAI) was applied to measure the volume occupied by granules in analog rice. The analog rice (10 g) sample was suspended in distilled water (100 mL) at room temperature for 30 min and stirred gently during this period for 15 min. Then centrifuged at 2000×g for 15 min. The supernatant liquid is carefully poured into the evaporating cup that has been tarred. The remaining suspension was weighed and the WAI was calculated as the weight obtained per gram of solids.

To analyze the water solubility index (WSI), 10 g of the sample was placed in a cap test tube with 100 mL of distilled water. The tube was mixed regularly and kept in a water bath at 60°C for 30 min. After cooling to room temperature, the tube was centrifuged

(Thermo Fisher Scientific in Waltham, MA, USA) at 2000×g for 30 min, and the weight of the sediment was measured. The supernatant was dried in an oven at 100°C until the weight remained constant, and the wet and dry weights of the paste and supernatant were recorded to determine swelling and solubility.

Contact Angle Analysis

Contact angles analysis was referred to Read *et al*.[24] The analysis was carried out using an OCA-20 contact angle analyzer (DataPhysics Instruments GmbH, Filderstadt, Germany) with the method used being the captive bubble method at room temperature and 35% humidity. The procedure used in this method is the lens to be hung carefully in a circle in a lens holder so that the anterior surface of the lens faces directly down into the chamber and the lens is kept in a clean condition. Air bubbles were expelled from a blunt-tipped steel needle with a diameter of 1.65 mm which was positioned 2 mm just below the tip of the lens. Gradually the bubble increased by 0.1 mL/s using OCA-20 automated bubble delivery until the lens touched the surface. The angle calculation is carried out by increasing the air bubble at a rate of 0.12 mL/s until the volume reaches 3 mL, followed by decreasing the volume until the bubble is separated from the lens surface. All processes were recorded using digital film connected to a computer and carried out in triplicate.

Consumer Acceptance Analysis

Consumer acceptance analysis was referred to Sumardiono *et al*.[9] Untrained panelists were executed to ensure whether cooked analog rice was acceptable to consumers. The analog rice was cooked with the boiling method by soaking the analog rice in a pot with mineral water until the water level reached 2 cm above the surface of the rice. Afterward, the analog rice was boiled (100°C) for about 10 min until the rice absorbed water and the analog rice cooked perfectly. The analog rice was cooled before the consumer acceptance analysis on employing untrained panelists was performed. The analog rice quality was assessed in terms of taste, aroma, color, and texture using a numerical scale. This test was also intended to determine consumer acceptance analysis for cooked analog rice. This study was approved by the ethics committee of Semarang State University with number 243/KEPK/EC/2023 declared to meet the standards and operational guidance for ethical review of health-related research with human participants from CIOMS and WHO. Panelists responded by using numerical indicators, i.e., 2 (very poor), 4 (poor), 6 (fair), 8 (good), and 10 (very good). Forty people were involved as panelists aged 20 to 25, comprising 20 males and 20 females. Consumer acceptance analysis was analyzed in communities around Gunung Pati, Semarang, Indonesia. All the involved panelists agreed to participate in this study by signing the informed consent form.

Color

The color of analog rice is identified using the chromameter CR-400 instrument (Konica Minolta, Tokyo Japan). Hunter L (lightness), a (redness), and b (yellowness) were determined. Whiteness Index (WI), chroma (C), and hue (ho) are calculated using the following equations:

$$\text{Whiteness Index (WI)} = 100 - \sqrt{(100 - L)^2 + a^2 + b^2} \quad ...(2)$$

$$\text{Chroma (C)} = \sqrt{a^2 + b^2} \quad ...(3)$$

$$\text{Hue } (h^o) = \arctan \ b/a \quad ...(4)$$

In addition, a photo of the analog rice sample is taken with the XT-3 camera (Fujifilm, Japan) using a shutter speed of 1/100 and an aperture of f/4.

Statistical Analysis

The statistical analyses were conducted using OriginPro software, provided by OriginLab (OriginLab Corporation at Northampton, MA, USA). and were expressed ± were presented as standard deviation. This research uses analysis of variance (ANOVA) using IBM SPSS Statistics for Windows, Version 23.0 (IBM Corp, Armonk, NY, USA) to analyze the significance value with a 0.05 level of significance. ($P<0.05$).

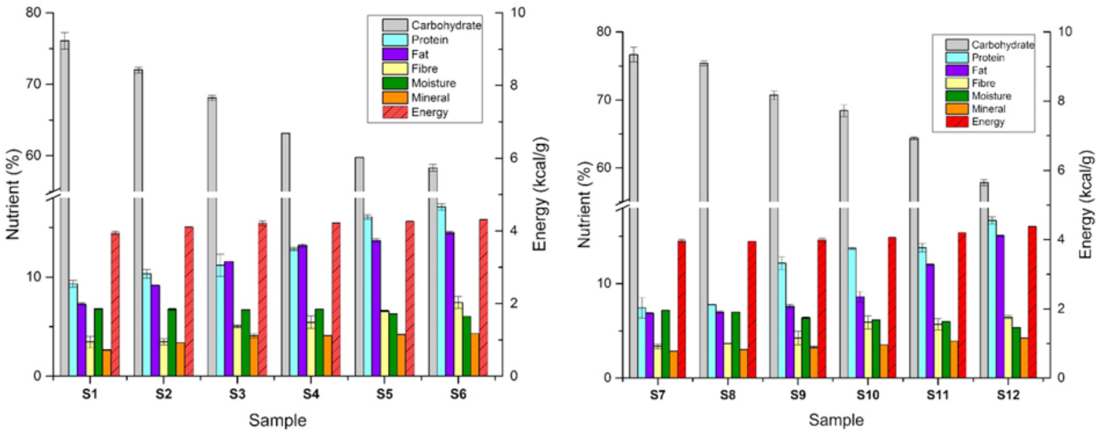
Results and Discussion

Effect of Flour Composition on The Nutritional Value of Analog Rice

Carbohydrate

Fig. 1 shows that the analog rice with the highest carbohydrate content was S7 (100% white sorghum without using soybean mixture). In vice versa, the lowest carbohydrate concentration was found in S12 (a mixture of 50% white sorghum and 50%

soybean flour). The concentration of analog rice carbohydrates is affected by the carbohydrates of each raw material used. Red sorghum and white sorghum have a similar carbohydrate concentration of roughly 76.61%, while soybean flour has a lower concentration of carbohydrates, i.e., 37.38%. The decrease in carbohydrate concentration when adding 50% soybean flour was quite significant (P>0.05). The mixture of the analog rice with various compositions of soybean flour aimed to investigate the rice with the highest nutritional value from all the 12 samples tested. The carbohydrate value of analog rice is generally lower than that of paddy rice, which reaches 80.00%, so this analog rice can be used as a good alternative staple food with high nutrition.[25] Carbohydrates of 50% are still considered sufficient to meet daily calorie needs. On the other hand, amylopectin and amylose in sorghum as raw materials of analog rice were reported to reach up to 34.13% and 18.57%, respectively.[26] While soybean flour as an addition in analog rice contains amylopectin and amylose up to 20.22% and 50.21%, respectively.[27] As amylose cannot be digested by enzymes and cannot be absorbed as glucose by the intestine, it does not cause a buildup of glucose in the body.[28] The high concentration of amylopectin and amylose compounds leads to a lower glycemic.[29] In addition, the carbohydrate of analog rice, which is lower than rice, can help prevent the development of type-2 diabetic and be used as a good diet. In this research, S6 and S12 were appropriate to consume by diabetics at the right dose. Carbohydrates are known to have a greater impact on insulin levels compared to protein and fat.[30] High insulin can have an impact on reducing the sense of fullness and will influence consumption behavior.[31] Low carbohydrates help type 2 diabetics due to they minimize drastic spikes in blood sugar after meals. When people with 2 diabetics consumes fewer carbohydrates, it means the amount of glucose the body has to deal with is also reduced.[32] As a result, blood sugar remains more stable, and diabetics can more easily control their blood sugar levels.



(a) (b)

Fig 1: Nutritional values of the analog rice (a) Analog rice with red sorghum varieties, (b) Analog rice with white sorghum varieties

Protein

Fig. 1 shows that the highest protein concentration of the red sorghum sample was in sample S6 (a mixture of 50% soybean flour), reaching 17.07%. In the white sorghum analog rice sample, the highest protein concentration was in sample S12 (a mixture of 50% soybean flour), i.e., 16.67%. In the samples of the two variants of sorghum without the addition of soybean flour, the protein of each red and white sorghum only reached 9.315% and 7.44%, respectively. Since soybean flour has a fairly high protein concentration of about 28.80%. Thus, adding soybeans as a raw material can enhance the protein content in analog rice. Protein is one of the essential components to support the needs of human life as a source of energy.[33] Protein could also form components of enzymes and hormones that can maintain the function of human cells and organs' growth.[34] Protein also plays a vital role in maintaining the acid-base fluid balance in the body and synthesizing antibody substances.[35] High protein in food also leads to a low glycemic index and inhibits glucose absorption in the body, so it is beneficial for diabetic patients and as a diet food.[36]

Fat Content

Fig. 1 illustrates that the highest fat content in the analog rice with red sorghum and white sorghum as the raw material were S6 and S12 of 17.07% and 16.67%, respectively. It is evident that the fat concentration of the analog rice rises with the addition of soybean flour concentration. Before being processed into analog rice, the fat concentration of red sorghum, white sorghum, and soybeans were 4.33%, 2.85%, and 20.07%, respectively. A relatively high-fat concentration in soybeans and adding soybean oil during the production of analog rice also affect the fat concentration in the analog rice itself. The recommended total fat for daily food needs ranges from 20-35%.[37] Fat is a component of organic compounds and is included in the lipid group and one of the nutrients humans need as energy sources.[38,39] Compared to animal fats, plant fats contain little saturated fat and low cholesterol.[40] In sorghum grain, there are 85.06 to 86.67% polyunsaturated fatty acids such as linoleic acid and linolenic acid.[41] Meanwhile, polyunsaturated fat in soybeans in the form of linoleic acid reaches 53% of total fat.[42] Substantial PUFA test evidence reported that it has a significant beneficial effect on inducing cardiovascular effects.[43]

Fiber

The highest fiber concentration recorded in red and white sorghum artificial rice samples were S6 and S12 of 14.47% and 15.08%, respectively (Fig. 1). In vice versa, the lowest fiber was 3.44%. The increase in fiber value in analog rice was affected by the addition of soybean flour. Sorghum and soybeans already have a relatively high fiber content. However, the total fiber concentration dropped after being processed into analog rice, mainly due to steaming and drying. Processing the analog rice with heat can increase the degree of recrystallization and cross-link.[44] The high fiber is crucial in lowering the Glycemic Index (GI).45 Consuming high-fiber foods is beneficial for health and effectively lessens the risk of diseases.46 Additionally, dietary fiber intake is known to lead to a healthier gut microbiome, a more ideal body weight, more stable metabolism overall, and is associated with a reduced risk of developing cardiovascular disease.[47]

Moisture Content

Fig. 1 shows that the water content of analog rice ranges from 5.345- 6.805%. Water content is affected by the process of drying and storage of analog rice. In general, the maximum moisture content in dry food is 14% due to bacterial and fungal growth's influence on these food ingredients.[9] The drier the rice, the more inhibited the fungus growth the storage time will be longe.[48] Low water concentrations determine food quality in terms of softening, hardening, decomposition, and swelling or shrinkage caused by phase transitions or dissolution.[49]

Mineral

Minerals are one of the essential components needed for human metabolism.[50] Minerals come from the earth, cannot be produced by living organisms, and can be absorbed easily by plants.[51] Fig. 1 displays that the highest minerals of the analog rice of the red sorghum and white sorghum were sample 6 (addition of 50% soybean) 4.31%, and sample 12 (addition of 50% soybean flour), i.e., 4.22%, respectively. In general, soybean seeds have a higher mineral content of roughly 4.31% than sorghum grains. Typically, foodstuffs minerals consist of potassium, calcium, iron, and other minerals. The sorghum grain contains micronutrient minerals such as potassium (18.26-26.66%), sodium (1.87-3.24%), magnesium (5.86-10.97%), calcium (0.95-1.69%), phosphorus (7.41-18.18%).[52] Whereas soybean flour contains micronutrient calcium up to 0.303%, magnesium up to 0.252%, iron up to 0.016%, sodium up to 0.03%, zinc up to 0.27%, and phosphorous up to 6.95%.[53] Micronutrient minerals in foodstuffs have many benefits, such as enzyme cofactors, forming heart muscle activity, muscle and nerve function, and energy metabolism.[54] According to the National Food and Drug Agency of the Republic of Indonesia (BPOM) (2019), the minimum mineral content in food is 2% per serving.[55] However, this study only analyzed the total minerals.

Calorie Calculation

According to Fig. 1, the calorie of the analog rice ranged from 3.94 to 4.33 kcal/g. The calorific value rises with the addition of soybean flour substitution. This phenomenon can be associated with soybean flour's relatively high fat and protein content. Foods with energy density between 4-9 kcal/gram are classified as high-density foodstuffs.[56] Compared to rice, the energy density value of sorghum rice is higher. This result is because sorghum analog rice's fat and protein values were higher than rice. Foods with a low energy density usually have high water and low-fat content.[57]

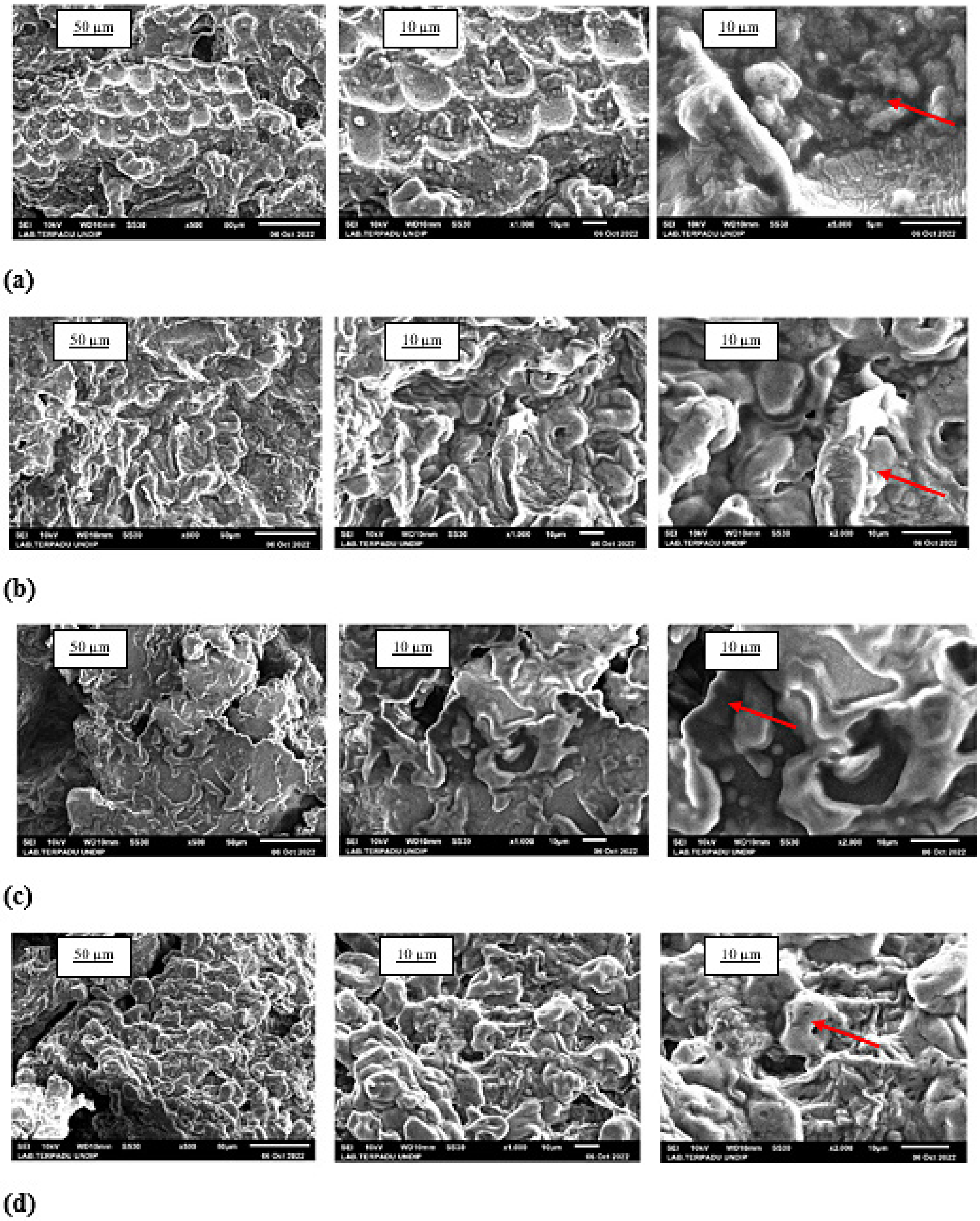


Fig 2: The morphological structure of analog rice (500x, 1000x, and 2000x), (a) Analog rice of S1, (b) Analog rice of S6, (c) Analog rice of S7, (d) Analog rice of S12

Morphology of Analog Rice

Fig. 2 shows the morphology of the analog rice with red sorghum and white sorghum as the raw material, respectively. Meanwhile, Fig. 2(a) and 2(c) depict the morphology of the analog rice without fortification of soybean flour in each type of sorghum varieties. From the morphological analysis, it can be seen that the addition of fortification with soybean flour affects the structure of the resulting analog rice. The red arrows in Fig. 2 show the pores in each of the analog rice. The addition of soybean flour in the analog rice process resulted in a dense structure. From Fig. 2(a) and 2(c) it can be seen that analog rice without the addition of soybean flour still has cavities. Meanwhile, in Fig. 2(b) and 2(c), the structure of the analog rice has few cavities and the structure is lumpier. This phenomenon happened to the two tested variants, i.e., red and white sorghum variants. The difference in morphology of the analog rice is related to the greater protein concentration due to the addition of soybean flour. Protein and starch in foodstuffs during the steaming process in analog rice production can interact, and a gelatinization process occurs.[58] The higher the protein in the food, the higher the gelatinization either partially or entirely when heated in the analog rice drying process during the drying process. In addition, the morphological structure of analog rice is also influenced by the water content in the analog rice production process. The less water content in the raw material will affect the composite flour not swelling properly.[59] On the other hand, the extrusion process does not affect the morphological structure of analog rice due to the extrusion process for production of analog rice uses the same mold size.

Water Adsorption Index (WAI), Water Solubility Index (WSI), and Contact Angle

Fig. 3 displays that adding soybeans to analog rice reduced the WAI in each red and white sorghum variant. However, there was no dramatic downward trend between 0% and 20%. WAI describes the ability of analog rice to absorb water in the granules. Adding 50% soybean flour resulted in a WAI value of 14.29 ± 0.23 and 12.96 ± 0.12 in red and white sorghum, respectively. In general, the drop in WAI was affected by the added protein concentration and the reduced starch in analog rice when soybean flour was added.[60] This phenomenon occurs due to the formation of cross-links between starch and protein during the analog rice manufacturing process, which causes a decrease in water absorption.61 Meanwhile, the WSI in all samples did not change significantly ($P < 0.05$) in the two types of analog rice, i.e., red and white sorghum variants.

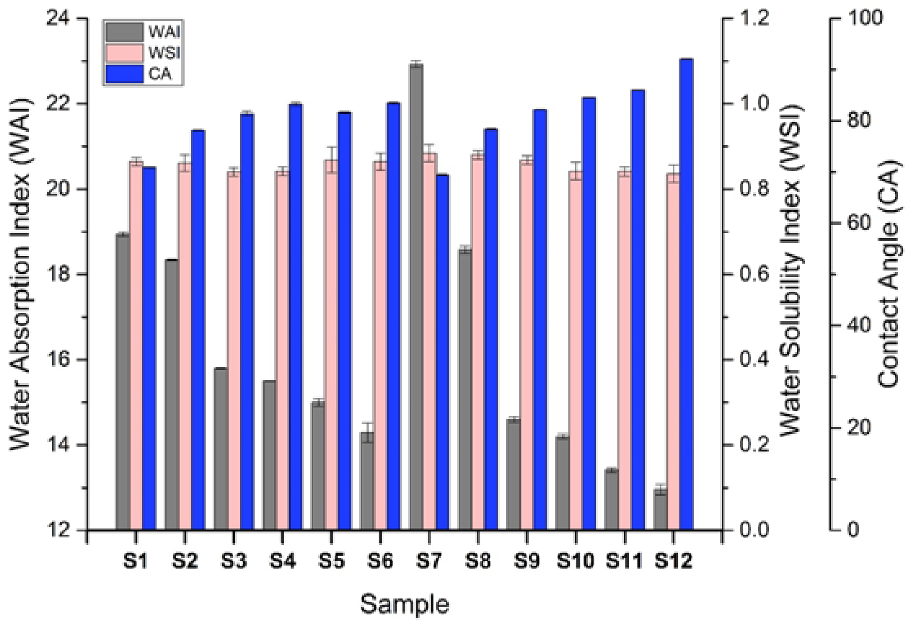


Fig 3: Water Adsorption Index (WAI), Water Solubility Index (WSI), and Contact Angle

Angle

Contact angle analysis is a method to analyze whether a material is more dominant towards hydrophilicity or hydrophobicity. Measurement with contact angle can also be used to determine the interaction between polar and non-polar in a suspension. From Fig. 4, it can be seen that the most hydrophilic analog rice with the raw material of red sorghum rice was S7, with a contact angle value of 69.50. The addition of soybean flor affects analog rice to be more hydrophobic, and this is evidenced by the increasing contact angle value and decreasing WSI value. This result might occur due to the adding soybeans will add protein and increase the gelatinization of the analog rice after processing. When a protein undergoes gelatinization, structural changes occur that affect the physicochemical properties of the protein.[62] Apart from that, the higher the protein in analog rice, the higher the denaturation process occurs during the drying process. The denaturation process results in a decrease in the WSI value of food products.[63] The denaturation process will inhibit the swelling of starch which results in the soluble components decreasing.[64] The addition of soybean substitutes to analog rice led to more hydrophobic rice, maybe due to the high-fat content in soybeans affecting the water absorption of analog rice.

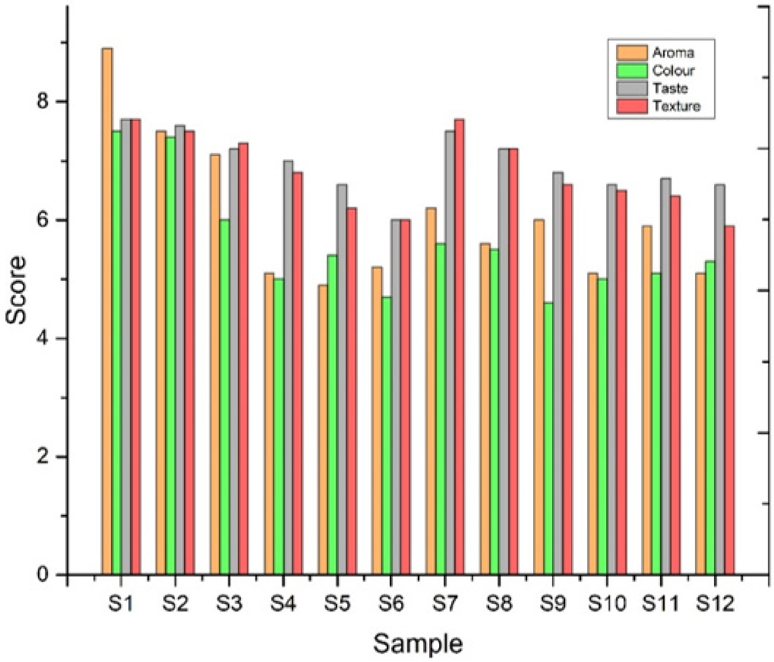


Fig 4: Consumer Acceptance Analysis of Analog Rice

Organoleptic Analysis of Analog Rice

Aroma

Aroma is one of the crucial parameters in the consumer acceptance test. If the aroma of food is too bland, it can recede the taste and is not good in foodstuff. Conversely, too strong aromas sometimes cause consumers to dislike the food. Thus, it is necessary to analyze how consumers like the aroma of a food ingredient test. The aroma of analog rice is influenced by numerous factors, such as the raw material factor, the substitute material type factor, and the factor when producing analog rice. From Fig. 4, it can be seen that the sample with the highest value for the aroma assessment was S1 (8.9) and S7 (6.2), with red sorghum and white sorghum as the raw material, respectively. The decrease in the aroma rating can be linked to the addition of soybean flour as a substitute for analog rice. In general, the more soybean flour added, the more unfavorable the aroma rating. Soybeans processed into flour produce less desirable aromas.[65] In addition, the heating process in the production of analog rice causes the protein to be denatured and triggers the Maillard reaction, which results in shifts to soybean flour.[66] While food ingredients containing high protein are heated, covalent bonds will form between the carbonyl groups and free amino groups, thus affecting foodstuf aroma.[67] Meanwhile, soybean flour produces a very strong beany aroma which makes food products containing soybean more difficult for accepting to the consumers.[68]

The color of foodstuff ingredients is an indicator of consumer acceptance. The color of the foodstuff that is less attractive causes the food to be difficult to be accepted by consumers.[69] Fig. 4 shows that according to consumers, sample S1 obtained the highest score of up to 7.4 for analog rice made from red sorghum. The score of S7, which was made from white sorghum, was only 5.6. Meanwhile, the consumer acceptance scores of analog rice added to soybean flour tended to decrease. This phenomenon can be linked to consumers' preference for darker brownish colors than pale colors. From Table 3, it can be seen that based on the chromameter results, analog rice from red sorghum raw material produces a darker color with a Whiteness Index value of 27.23 ± 0.027. The addition of soybean flour affects the color of the analog rice. The higher the concentration of soybean flour added, the more it influences the Whiteness Index value, with the highest value obtained in S6 with a value of 46.11 ± 0.010. However, in the case of white sorghum raw material, there is not much significant change ($P<0.05$) in the Whiteness Index value. Overall, the brown color of analog rice is influenced by the raw materials used.[70] In addition, there is an enzymatic browning reaction process during analog rice production.[71]

Table 3: Color Value of Analog Rice

Color Value	L (white -ness)	a* (red -ness)	b* (yellow -ness)	Whiteness index	Chroma (C)	Hue (ho)	Pictures of Sample
S1	27.99 ± 0.028	6.28 ± 0.007	8.30 ± 0.007	27.23 ± 0.027	14.24 ± 0.001	0.974 ± 0.001	
S2	29.82 ± 0.007	5.52 ± 0.028	8.61 ± 0.098	29.08 ± 0.015	10.40 ± 0.061	0.923 ± 0.007	
S3	36.78 ± 0.008	5.19 ± 0.028	11.17 ± 0.028	35.59 ± 0.001	10.22 ± 0.039	1.000 ± 0.001	
S4	36.87 ± 0.007	4.71 ± 0.035	11.78 ± 0.035	35.60 ± 0.003	12.32 ± 0.017	1.135 ± 0.003	
S5	37.40 ± 0.009	5.10 ± 0.014	11.35 ± 0.007	36.18 ± 0.007	12.69 ± 0.001	1.190 ± 0.001	
S6	48.50 ± 0.007	4.61 ± 0.070	16.64 ± 0.062	46.11 ± 0.010	12.44 ± 0.087	1.148 ± 0.003	
S7	44.54 ± 0.636	4.22 ± 0.084	13.64 ± 0.014	42.79 ± 0.614	17.26 ± 0.036	1.300 ± 0.004	

S9	39.12 ± 0.007	4.05 ± 0.007	12.83 ± 0.070	37.65 ± 0.007	13.45 ± 0.065	1.264 ± 0.002	
S10	44.24 ± 0.007	3.61 ± 0.035	15.91 ± 0.014	41.91 ± 0.008	16.32 ± 0.005	1.347 ± 0.002	
S11	41.76 ± 0.014	5.01 ± 0.021	16.46 ± 0.007	39.26 ± 0.017	17.21 ± 0.012	1.275 ± 0.001	
S12	41.34 ± 0.028	3.94 ± 0.056	15.18 ± 0.056	39.27 ± 0.045	15.68 ± 0.068	1.316 ± 0.002	

Taste

Taste is the main parameter of the assessment of food. Good taste will make consumers continue consuming food products.[72] Fig. 4 shows that all samples of analog rice are acceptable to consumers with a score above 6. The highest score of analog rice was sample S1 (7.7) with red sorghum as the raw material and sample S7 with white sorghum as the raw material (7.5). Analog rice, without the addition of soybean flour substitutes, produces a taste almost similar to native rice. In contrast, according to consumer assessment, the taste value tends to decrease when soybean flour is added as a substitute, with the lowest value of 6 in sample S6. The added soybeans have a plain and nutty flavor, which may result in less interest from consumers as a substitute for rice.[73]

Texture

Fig. 4 depicts that the texture of the analog rice has a reasonably good average score, with the highest value for red and white sorghum raw materials in samples S1 and S6 reaching 7.7. Similar to the other parameters, adding soybean flour to analog rice led to a reduction in the score of the rice texture. Soybean flour has been widely used as an additional food ingredient, such as bread making.[74] The addition of soybean flour can improve the texture of the bread to make it crumblier and crustier.[75] However, adding high concentrations of soybean flour to analog rice causes the rice to taste harder, so consumers accept it less.

Conclusions

In terms of nutritional value, the best analog rice sample was sample S6 with red sorghum as the raw material and S12 with white sorghum as the raw material and substituted with 50% soybean flour. Sample S6 contained 58.29% ± 0.480 carbohydrates, 17.07% ± 0.311 protein, 14.47% ± 0.155 fat, and 7.43% ± 0.601 fiber, while sample S12 had 57.85% ± 0.473 carbohydrates, 16.67% ± 0.381 protein, 15.08% ± 0.084 fat, and 6.44% ± 0.169 fiber. Foods with low carbohydrates and high protein are helpful for consumption in people with diet programs and those at risk of obesity. The addition of soybean flour also affected the physical properties of analog rice, resulting in a denser morphological structure in both red and white sorghum raw materials. The addition of soybean substitution resulted in a decrease in the water adsorption index. Water solubility index and hydrophilicity did not have a significant effect when soybean flour substitutes were added. All analog rice can be accepted by consumers with a classification of above sufficient. However, adding soybean flour as a substitute for analog rice was less attractive to consumers than analog rice without substitutes. For future studies, it is necessary to further develop the pretreatment method for soybean flour as a fortification of analog rice so that analog rice is preferred by consumers with good nutritional value.

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Conflict of Interest

The author(s) declares no conflict of interest

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