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PHYSICOCHEMICAL CHARACTERIZATION OF PORANG TUBERS (*Amorphophallus muelleri*) ANALOG RICE WITH THE ADDITION OF *Spirulina platensis*

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Abstract

Analog rice is a functional food designed to resemble conventional rice but is produced from non-rice sources. This study developed porang analog rice enriched with *Spirulina platensis* to improve its nutritional and antioxidant properties. The variation of four concentrations of *S. platensis* (0, 1.5, 3, and 4.5%) was evaluated using a completely randomized design. Sensory evaluation indicated that the 1.5% formulation was significantly preferred (p<0.05) and selected for further analysis. On a dry basis, the optimized product contained 92.2% carbohydrates, 2.73% protein, and 57% of dietary fiber. Its cooking time was 7.53 min, with 129.2% water absorption and a bulk density of 0.47 g/mL. Phytochemical screening confirmed the presence of flavonoids, phenolic compounds, and saponins. The antioxidant activity was classified as very strong, with an IC_{50} of 47.10 ppm, demonstrating significant radical scavenging potential. The novelty of this research lies in the unique combination of porang, potato, and *Spirulina*, which has not been previously applied in the development of analog rice. This formulation integrates the high dietary fiber content of porang, the starch functionality of potato, and the bioactive compounds of *Spirulina*, resulting in a product with enhanced nutritional quality and functional properties. Overall, porang analog rice with *Spirulina* showed strong consumer acceptance and bioactivity, highlighting its potential as a promising functional food.

Keywords: antioxidant, bioactive, dietary fiber, potato starch, sensory test

Karakterisasi Fisikokimia Beras Analog Porang (*Amorphophallus muelleri*) dengan Penambahan *Spirulina platensis*

Abstract

Beras analog merupakan pangan fungsional yang dirancang menyerupai beras konvensional namun diproduksi dari bahan non-beras. Penelitian ini mengembangkan beras analog porang yang diperkaya Spirulina platensis untuk meningkatkan nilai gizi dan aktivitas antioksidan. Variasi empat konsentrasi *S. platensis* (0%, 1,5%, 3%, dan 4,5%) diuji menggunakan rancangan acak lengkap. Hasil uji sensori menunjukkan bahwa formulasi 1,5% paling disukai secara signifikan (p<0,05) sehingga dipilih untuk karakterisasi lebih lanjut. Berdasarkan basis kering, produk terpilih mengandung 92,2% karbohidrat, 2,73% protein, dan 57% serat pangan. Waktu pemasakan 7,53 menit dengan daya serap air 129,2% dan densitas kamba 0,47 g/mL. Skrining fitokimia mengonfirmasi adanya flavonoid, fenol, dan saponin. Aktivitas antioksidan tergolong kuat dengan nilai IC_{50} sebesar 47,10 μg/mL menunjukkan kemampuan penangkal radikal yang signifikan. Kebaruan penelitian ini terletak pada kombinasi unik porang, kentang, dan *Spirulina* yang sebelumnya belum pernah diterapkan dalam pengembangan beras analog. Formulasi ini mengintegrasikan serat pangan tinggi dari porang, fungsi pati dari kentang, serta senyawa bioaktif dari *Spirulina* sehingga menghasilkan produk dengan kualitas gizi dan sifat fungsional yang lebih baik. Secara keseluruhan, beras analog porang dengan *Spirulina* menunjukkan penerimaan konsumen yang baik dan bioaktivitas tinggi sehingga berpotensi dikembangkan sebagai pangan fungsional yang menjanjikan.

Kata kunci: antioksidan, bioaktif, serat pangan, tepung kentang, uji sensori

INTRODUCTION

The increasing global demand for functional foods has accelerated innovation in staple food alternatives using underutilized and nutrient-rich ingredients. Analog rice, a rice-like product designed to mimic the shape and texture of conventional rice, offers flexibility in modifying its nutritional composition using diverse raw materials and processing techniques. Analog rice, typically produced via extrusion or molding, enables the incorporation of functional ingredients, dietary fiber, and plant-based proteins into a staple format widely consumed across Asia and Africa (Florie *et al.,* 2024). This approach not only improves dietary diversity but also provides potential solutions to address micronutrient deficiencies and diet-related metabolic disorders in rice-dependent populations.

Previous studies have explored the use of tubers, legumes, cereals, and composite flours to enhance protein content, reduce the glycemic index, and increase functional compounds. However, limited research has examined the synergistic effects of combining underutilized local crops with microalgae, particularly in the context of analog rice formulations. However, the functional interactions, technological feasibility, and health implications of such combinations remain largely unexplored. For example, Salsabila *et al.* (2025) investigated *Gracilaria*-based analog rice with an emphasis on kinetic modeling of quality deterioration and shelf-life prediction, while Purwaningsih (2022) focused on the characterization of dietary fiber and bioactive constituents derived from seaweed. In contrast, the present study employs porang and potato as complementary fiber sources, further enriched with *Spirulina platensis*, thereby addressing the gap in multicrop analog rice development and establishing a distinct novelty in formulation and functionality.

In this study, porang (*Amorphophallus muelleri*) and potato (*Solanum tuberosum*) emerged as promising base ingredients. According to Setiarto *et al.* (2024), porang is rich in glucomannan, a soluble dietary fiber with strong water-binding, gel-forming, and thickening properties. Glucomannan is clinically associated with reduced glycemic response and improved gut health, making porang relevant for diabetes prevention and weight management. However, porang is low in protein, which may limit the nutritional profile of its final product. Potatoes contribute starch and small amounts of protein, improving both texture and nutritional balance. A porang–potato combination in a 1:1 ratio was strategically used to optimize the processability, sensory quality, and nutritional composition.

To further enrich its bioactivity, *Spirulina platensis* was incorporated. Spirulina is a blue-green microalga widely recognized for its high protein content (57–65%) and antioxidants, such as phycocyanin, phenolic compounds, and essential micronutrients. Trilaksani *et al.* (2015) reported its potential antioxidant activity (IC_{50} 288.68 ppm), while Tessier *et al.* (2021) highlighted its high protein quality with a PDCAAS of 84% and a chemical score of 0.98. In addition to protein fortification, Spirulina supplementation has been linked to improved immune function, anti-inflammatory activity, and potential benefits for cardiovascular health.

Although porang, potato, and Spirulina have been individually studied, there is limited evidence on their combined application in analog rice. However, little is known about how this composite matrix influences physicochemical quality, antioxidant potential, and functional synergy. Previous studies have rarely examined the integration of porang–potato flour with Spirulina in analog rice formulations. Therefore, this study aimed to develop and characterize porang–potato analog rice enriched with different concentrations of Spirulina, focusing on its physicochemical properties, antioxidant activity, and potential as a functional food.

MATERIALS AND METHODS

Formulation of Uncooked Porang Analog Rice with Spirulina

The process of making uncooked porang analog rice with spirulina in this study was adapted from Zulfa *et al.* (2023) with modifications. Porang flour was obtained from El Masta (Indonesia) and sieved to 60 mesh before use. Potato flour was sourced from Food Mall Depok (Indonesia), while *Spirulina platensis* powder was purchased from PT Algaepark (Indonesia) and stored in airtight containers until processing.

The process began by preparing the dough using a 1:1 ratio of porang flour to potato flour, 1% glycerol monostearate (GMS) as an emulsifier, and *Spirulina platensis* powder at three concentrations: 1.5%, 3%, and 4.5%. The dry ingredients were mixed thoroughly, followed by the gradual addition of hot water until a cohesive and elastic consistency was achieved.

The dough was then manually molded into rice-like granules using a noodle maker as an alternative to extrusion, ensuring a uniform particle size. After shaping, the analog rice was steamed at 90–100 °C for 15 min and dried in an oven at 90 °C for 120 min. The final uncooked analog rice was rehydrated in hot water for 5–7 min to obtain ready-to-eat rice. The research flow is shown in Figure 1.

Hedonic Quality Analysis

A hedonic quality test was conducted to assess consumer preferences for specific sensory attributes of the product. The organoleptic parameters evaluated included

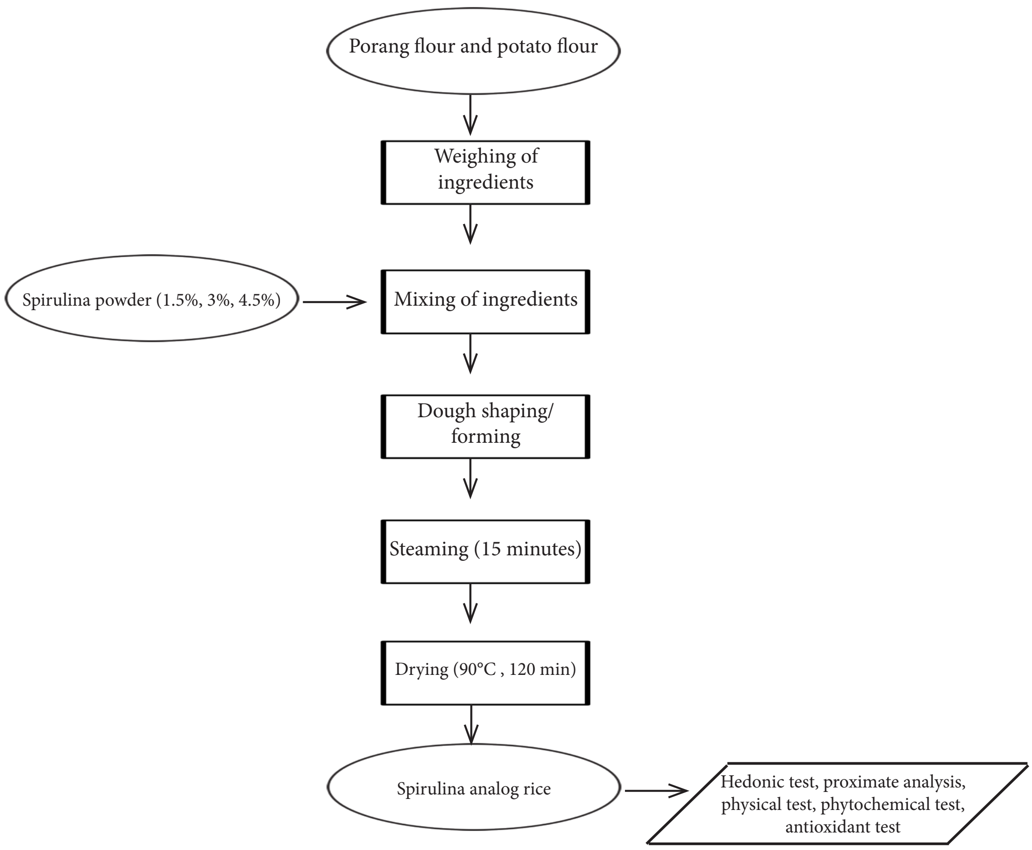


Figure 1 Flow diagram of spirulina analog rice production

color, texture, aroma, taste, and the overall appearance. The sensory evaluation of the cooked porang analog rice with spirulina was performed by 30 untrained consumer panelists, consisting of 18 females and 12 males, aged between 20 and 25 years, using a 9-point hedonic scale, ranging from "dislike extremely" (1) to "like extremely" (9). The selection of general consumers aimed to reflect actual market responses. This method is based on the 9-point hedonic scale developed by Peryam and Pilgrim (1957), which has since become the standard for preference testing in food-sensory analysis. Furthermore, it aligns with the standards for sensory evaluation outlined in SNI 01-2346-2006, which recommends a minimum of 20–30 panelists for hedonic tests to ensure the reliability and statistical relevance of the results.

Proximate Analysis

Proximate analysis included moisture content using the oven method (AOAC, 2012), ash content (AOAC, 2012), protein content (AOAC, 2005), dietary fiber (AOAC, 1995), fat content (AOAC, 2005), and carbohydrate content (AOAC, 2019). Proximate analyses were performed in triplicate.

Cooking Time Analysis

Fifty grams of uncooked porang analog rice with Spirulina was soaked in boiling water at a water-to-rice ratio of 1:1. Unlike conventional rice, this analog rice was steamed and oven-dried during its production. The cooking (rehydration) time was measured using a stopwatch from the moment the rice granules were immersed until they reached the defined endpoint of cooking. Cooking completion was determined when the granules showed complete rehydration, marked by the disappearance of the hard core and the development of a soft, cohesive texture.

This procedure was adapted from Kurniasari *et al.* (2020) with modifications to suit the physical characteristics of porang analog rice and spirulina. Additionally, similar rehydration approaches in other studies have shown that instant analog rice products typically achieve optimal texture after soaking in hot water for a few minutes, depending on the formulation and drying method.

Water Absorption Capacity Analysis

According to Sosulski (1962), five grams of uncooked porang analog rice with spirulina were weighed and soaked in warm water at 80°C for 5 min. After soaking, the rice was drained and weighed. The water absorption capacity was calculated by subtracting the initial weight of the rice from its weight after soaking.

Color Analysis

The color of uncooked porang analog rice with spirulina was analyzed using a colorimeter. The rice sample was placed into the device, and the color reader was applied to the surface of the sample. Readings were taken in terms of L^* (lightness), a^* (redness), and b^* (yellowness), and the target button was pressed. The displayed results were recorded (Yam and Papadakis 2004).

Bulk Density Analysis

According to Bhattacharya *et al.* (1972), a sample of uncooked porang analog rice with spirulina was placed in a 50 mL measuring cylinder. The rice was then removed and weighed again. Bulk density is expressed in g/mL or g/cm³ and can be calculated using the following formula:

$$\text{Bulk density (g/mL)} = \frac{m_{filled}(g) - m_{empty}(g)}{V_{bulk}\ (mL)}$$

Phytochemical Analysis

According to Farnsworth (1966), phytochemical testing includes the detection of alkaloids, phenols, flavonoids, saponins, steroids, and terpenoids. Alkaloids were indicated by the formation of brown precipitate with Wagner's reagent, red precipitate with Dragendorff's reagent, and white precipitate with Mayer's reagent. Phenols were indicated by the formation of a green or bluish-green color after reaction with $FeCl_3$ and HCl. The presence of flavonoids was indicated by the formation of red, yellow, or orange color upon reaction with $FeCl_3$. The presence of saponins was confirmed by the formation of stable foam lasting for 10 min after vortexing. Steroids were indicated by the formation of a green color, while triterpenoids were indicated by a red color after reaction with acetic anhydride and concentrated sulfuric acid.

Antioxidant Activity Test

The antioxidant activity was tested using the DPPH method. The test was performed using 10 mg of sample and 1 mg of ascorbic acid. A 0.1 mM DPPH reagent was prepared by dissolving 1 mg of DPPH in 25 mL methanol. The rice samples were diluted to concentrations of 100, 200, 300, 400, 500, 600, 700, 800, 900, and 1000 ppm. The solution was incubated for 30 min, and the absorbance was measured at a wavelength of 517 nm using a UV-Vis spectrophotometer (Banerjee *et al.* 2005). The antioxidant activity test was conducted in triplicate. The inhibition activity of Spirulina was calculated using the following formula:

$$\text{Inhibition (\%)} = \frac{A-B}{A} \times 100\%$$

Note:
A = absorbance of blank
B = absorbance of sample

The IC_{50} value was calculated using a linear regression equation, with the sample concentration as the x-axis and % inhibition as the y-axis, based on the formula Y = a + bX. The IC_{50} value was determined using the following equation:

$$IC_{50} = \frac{(50-a)}{b}$$

Data Analysis

The experimental design used in this study was a completely randomized design (CRD) with a single factor, namely, the concentration of *Spirulina platensis* (Kutner *et al.*, 2004). The treatments consisted of four levels: 0%, 1.5%, 3%, and 4.5%. Each treatment was replicated three times (n = 3) for proximate composition and antioxidant analyses, while sensory evaluation was conducted with 30 untrained panelists (n = 30).

Parametric data were first tested for normality using the Shapiro–Wilk test (Sugiyono, 2011). Homogeneity of variance was confirmed prior to the analysis. Data that met parametric assumptions were analyzed using one-way Analysis of Variance (ANOVA) to evaluate the effect of spirulina concentration. When significant differences ($p<0.05$) were observed, Duncan's Multiple Range Test was applied as a post hoc test to group the treatments (Montgomery, 2012).

Non-parametric data from the sensory evaluation were analyzed using the Kruskal-Wallis test (Sheskin, 2004). In cases of significant differences, pairwise comparisons were performed using the Mann–Whitney test to identify specific treatment differences in panelist preferences. The best treatment was determined using the De Garmo method (De Garmo, 1984), which integrates sensory and physicochemical parameters of the samples. All statistical analyses were performed using IBM SPSS Statistics version 25, and Microsoft Excel 2019 was used for data tabulation and visualization.

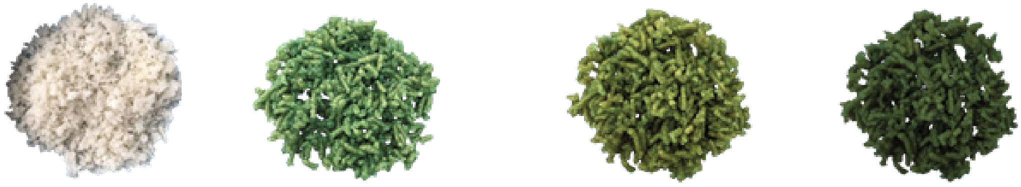
RESULTS AND DISCUSSION

Sensory Characteristics of Cooked Porang Analog Rice with Spirulina

Cooked porang analog rice with spirulina has a distinctive green color typical of spirulina, a slightly marine or umami aroma, a chewier texture than regular rice, and a generally neutral taste with a hint of savory flavor. Once cooked, the rice appears moister and more elastic than conventional rice. A sensory test was conducted with 30 panelists to assess color, texture, aroma, taste, and appearance. The spirulina concentrations were 0%, 1.5%, 3%, and 4.5%. The samples presented to the panelists during the hedonic test are shown in Figure 2

Sensory testing of cooked spirulina porang analog rice was conducted by 30 panelists with parameters including color, texture, aroma, taste, and appearance. The hedonic test results for the cooked porang analog rice are presented in Table 1.

The sensory evaluation of cooked porang analog rice with Spirulina, analyzed



(0%) (1.5%) (3%) (4.5%)

Figure 2 Appearance of cooked porang analog rice with spirulina

using the Kruskal–Wallis test followed by pairwise comparison via the Mann–Whitney U test, demonstrated that the incorporation of *Spirulina platensis* significantly influenced the hedonic responses of panelists across multiple sensory parameters. The treatments with 0%, 1.5%, 3%, and 4.5% spirulina exhibited statistically distinguishable profiles, with 1.5% spirulina consistently receiving the highest mean scores.

Specifically, the color attribute showed no significant difference between 0%and 1.5% spirulina, both of which were more favorably rated than 3% and 4.5% spirulina. The decrease in color acceptance at higher spirulina concentrations may be attributed to the intensified green pigmentation imparted by phycocyanin, which, although indicative of increased bioactivity, diverges from the conventional consumer expectations of rice appearance.

The sensory texture scores ranged from neutral to like (5.93–6.93). Products containing glucomannan can form gels, thicken, absorb, and bind water. Evaluation revealed that 0% and 1.5% spirulina retained significantly superior mouthfeel characteristics, while 3% and 4.5% spirulina were rated lower, likely due to microstructural changes associated with spirulina incorporation, such as reduced porosity or modified starch–protein interactions, which can influence hydration and softening behavior during cooking. According to Wang *et al.* (2023), higher spirulina concentrations affected the texture. Proteins with polysaccharide content exhibit functional properties such as emulsification, thickening, and water-binding, which contribute to increased viscosity and stability in food products.

The aroma scores ranged from neutral to like (5.87–7.13). The aroma and taste parameters followed similar trends, with rice with 1.5% Spirulina achieving the highest acceptability, whereas rice with 4.5% Spirulina was significantly less preferred. These outcomes may reflect the increased volatility and perceptibility of spirulina's inherent marine-like or umami-associated aroma compounds at higher inclusion levels, which could negatively influence overall flavor perception. According to Paraskevopoulou *et al.* (2024), spirulina has a fresh, slightly fishy scent caused by volatile compounds, such as C_6, C_8, and C_9 aldehydes, ketones, and alcohols.

Taste is influenced by chemical compounds, temperature, concentration, and the interactions between components. The taste scores ranged from neutral to like (6.10–6.90). According to Tietze (2004), higher spirulina concentrations tend to produce a more bitter taste, attributed to alkaloids and

Table 1 Hedonic test results of porang analog rice with spirulina (%)

Parameter	0	1.5	3	4.5
Color	6.93±1.14^{a}	7.07±1.33^{a}	6.83±1.59^{a}	6.07±1.91^{a}
Texture	6.60±1.38^{a}	6.93±1.41^{a}	5.97±1.56^{b}	5.93±1.61^{c}
Aroma	6.83±1.44^{a}	7.13±1.11^{a}	6.43±1.27^{a}	5.87±1.40^{b}
Taste	6.83±1.31^{a}	6.90±1.44^{a}	6.20±1.60^{a}	6.10±2.00^{a}
Appearance	7.33±1.29^{a}	6.63±1.49^{a}	6.57±1.67^{b}	6.03±1.88^{c}

Mean values in the same row with different superscripts indicate significant differences (α<0,05) tannins. Furthermore, the appearance scores ranged from neutral to like (6.03–7.33), with rice with 4.5% spirulina demonstrating the lowest visual acceptability, potentially due to chromatic saturation that may not align with consumer visual expectations of staple foods. The appearance of cooked porang analog rice spirulina differs from that of commercial analog rice owing to the production method, which uses granulation rather than extrusion. The main differences between these methods lie in the gelatinization and shaping processes used. Extrusion involves an extruder and results in oval-shaped grains, whereas granulation is manual and yields grains resembling real rice.

Collectively, these findings underscore the critical role of spirulina concentration in modulating sensory perceptions. Although *S. platensis* is a potent source of bioactive compounds, its incorporation at excessive levels compromises consumer acceptability. Therefore, a concentration of 1.5% is suggested as the optimal inclusion level, effectively enhancing the nutritional and functional profile of analog rice while maintaining the sensory attributes within an acceptable range for potential market adoption.

Among the four treatments evaluated, rice with1.5% *Spirulina platensis demonstrated* the most favorable sensory profile across all assessed parameters, including color, texture, aroma, taste, and appearance. Although no statistically significant differences ($p>0.05$) were observed in certain parameters, such as color, aroma, and taste, rice with 1.5% spirulina consistently exhibited the highest mean values, indicating a positive trend in overall panelist preference. Notably, rice with 1.5% spirulina maintained a balance between the functional presence of spirulina and consumer acceptability, avoiding the adverse sensory impacts observed at higher concentrations (3% and 4.5% spirulina), such as off-flavors, intensified marine aroma, and excessive green pigmentation. Based on this superior hedonic performance, rice with 1.5% spirulina was selected for subsequent analyses, focusing on its phytochemical composition and antioxidant capacity. This selection strategy aligns with the practical objective of developing functional food products that offer enhanced nutritional and bioactive properties and meet consumer preferences, thereby improving the feasibility of product acceptance in the market.

Chemical Characteristics of Uncooked Porang Analog Rice with Spirulina

The chemical characteristics were determined by proximate analysis and dietary fiber content determination. The results are presented in Table 2.

Based on Table 2, a one-way Analysis of Variance (ANOVA) was conducted to determine the effect of varying levels of *Spirulina platensis* on the chemical composition of uncooked porang analog rice. The parameters analyzed included moisture, protein, ash, carbohydrate, fat, and dietary fiber contents. Superscript letters indicate significant differences among treatments at $p < 0.05$, confirming the statistical impact of Spirulina addition.

Moisture content is crucial for determining shelf life and product stability. In this study, the moisture content significantly

Table 2 Chemical characteristics of uncooked porang analog rice with spirulina (%)

Parameter (%)	0	1.5	3	4.5
Moisture	43.3±0.51^{a}	57.1±0.10^{b}	51.4±0.14^{c}	30.5±0.49^{d}
Protein (db)	0.12±0.01^{a}	2.73±0.02^{b}	3.50±3.22^{c}	4.63±0.09^{d}
Ash (db)	2.50±0.03^{a}	2.77±0.02^{b}	2.94±0.02^{b}	3.03±0.04^{c}
Carbohydrate (db)	94.0±0.43^{a}	92.2±0.04^{b}	92.4±0.16^{c}	90.6±0.45^{d}
Fat (db)	2.01±0.02^{a}	1.92±0.00^{b}	0.95±0.00^{c}	1.57±0.00^{d}
Dietary fiber (db)	51.3±0.28^{a}	57.0±0.31^{b}	44.2±0.35^{c}	55.4±0.45^{d}

Different letter marks on the same line indicate significant differences decreased with increasing concentrations of *S. platensis*, ranging from 57.1 ± 0.10% (1.5% spirulina) to 30.5 ± 0.49% (4.5% spirulina). Moisture content decreased with increasing spirulina concentration due to the interactions between water and protein. The more *S. platensis* used, the higher the protein content, resulting in more hydrophilic proteins binding with water

The results revealed a significant increase in protein content with increasing levels of Spirulina. The control sample (0% spirulina) exhibited the lowest protein content (0.12 ± 0.01%), whereas 4.5% spirulina showed the highest protein content (4.63 ± 0.09%). This enhancement can be attributed to the high protein content of *Spirulina platensis*, a well-documented microalga rich in essential amino acids, which improves the nutritional quality of the analog rice. This is consistent with the findings of Raczyk *et al.* (2022), who reported that *S. platensis* powder contains approximately 71.34% protein. Moreover, the protein content in this study was higher than that of analog rice reported by Finirsa *et al.* (2022), which was 0.73%.

The ash content also increased significantly with spirulina addition, from 2.50 ± 0.03% (0% spirulina) to 3.03 ± 0.04% (4.5% spirulina), indicating a higher mineral content in the spirulina-enriched formulations. The ash content represents the total inorganic components. According to SNI 01-7111.1-2005, healthy food should not contain more than 3.5% ash. This aligns with the known composition of Spirulina, which contains abundant micronutrients such as iron, calcium, and magnesium.

Conversely, carbohydrate content showed a significant decrease as spirulina concentration increased, from 94.0 ± 0.43% (0% spirulina) to 90.6 ± 0.45% (4.5% spirulina). This trend reflects the substitution effect, where Spirulina, which is low in carbohydrates but high in protein and minerals, partially replaces carbohydrate-rich ingredients such as porang and potato flour. Porang flour contains glucomannan, a water-soluble dietary fiber polysaccharide made of glucose and mannose. According to Devi *et al.* (2020), potato flour also contributes 83.4 g/100 g carbohydrate content.

Fat content exhibited a fluctuating pattern, with a decrease from 0% spirulina (2.01 ± 0.02%) to 3% spirulina (0.95 ± 0.00%), followed by a slight increase at 4.5% spirulina (1.57 ± 0.00%). This variation may result from the interaction between Spirulina and the lipid composition of other raw materials, as well as the relatively low-fat content of Spirulina itself. Low fat can improve oxidative stability and extend the shelf life of the final product, as lipid reduction is closely associated with diminished susceptibility to rancidity and deterioration during storage.

The dietary fiber content also varied significantly across the treatments. The highest value was observed in rice with 1.5% spirulina (57.0 ± 0.31%), followed by rice with 4.5% spirulina (55.4 ± 0.45%), while rice with 3% spirulina had the lowest fiber content (44.2 ± 0.35%). The unexpectedly low fiber content in rice with 3% Spirulina may be attributed to the partial degradation of fiber components or reduced incorporation of Spirulina-derived fiber during processing, leading to lower retention compared to rice with 1.5% and 4.5% Spirulina. These fluctuations could be due to changes in the matrix structure and water-holding capacity as the ratio of Spirulina to other fibers shifts during formulation. According to Ekantari *et al.* (2017), *S. platensis* contains 24.81% total dietary fiber.

Physical Characteristics of Uncooked Porang Analog Rice with Spirulina

The physical analysis included water absorption, cooking time, bulk density, and color brightness, as shown in Table 3.

Table 3 presents the physical characteristics of uncooked porang analog rice with added spirulina. The data were statistically analyzed using one-way Analysis of Variance (ANOVA) followed by post hoc comparison (Duncan's multiple range test) to determine significant differences between treatments at a 95% confidence level, as indicated by differing superscript letters. The results demonstrated that increasing the concentration of *Spirulina*

Table 3 Physical characteristics of uncooked porang analog rice with spirulina (%)

Parameter	0	1.5	3	4.5
Cooking time (min)	6.70±0.42[a]	7.53±0.20[b]	8.03±0.25[b]	8.76±0.25[c]
Water absorption (%)	116.2±7.40[a]	129.2±3.55[b]	136.2±2.90[b]	160.4±2.22[c]
Bulk density (g/mL)	0.47±0.70[a]	0.47±0.08[a]	0.49±0.05[a]	0.54±0.06[a]
L*	76.00±1.13[a]	46.78±0.29[b]	41.67±0.06[c]	28.08±0.10[d]
a*	-0.33±0.02[a]	-3.13±0.04[b]	-4.13±0.02[c]	-2.05±0.01[d]
b*	4.39±0.06[a]	18.22±0.05[b]	19.32±0.07[c]	17.47±0.07[d]

Different letter marks on the same line indicate significant differences

platensis significantly affected all measured physical parameters, except for bulk density.

Cooking time progressively increased from 6.70 min in rice with 0% Spirulina to 8.76 min in 4.5% Spirulina ($p < 0.05$), suggesting that higher Spirulina content may contribute to the formation of a more compact or resistant matrix, likely due to its high protein and polysaccharide content. The cooking time is closely related to water absorption. The higher the water absorption, the shorter the cooking time, as the absorbed water accelerates the cooking process. Interestingly, this general relationship was not observed in uncooked porang analog rice with spirulina. Although the water absorption capacity increased with higher Spirulina concentrations, the cooking time also increased. This apparent contradiction can be explained by the elevated protein content of Spirulina, which requires additional thermal energy for denaturation and delays starch gelatinization, thereby extending the overall cooking time despite higher water uptake. According to Siaw *et al.* (2021), a significant portion of the heat energy is used for protein denaturation, thereby extending the time required for the product to become fully cooked.

The water absorption capacity also increased significantly from 116.2% (0% spirulina) to 160.4% (4.5% spirulina), indicating enhanced hydrophilic properties, potentially attributed to the bioactive compounds present in spirulina. According to Shi *et al.* (2023), water absorption affects the eating quality, as insufficient absorption may result in a slightly hard and coarse texture, whereas excessive absorption can lead to a sticky texture.

The bulk density remained statistically unchanged across all treatments, implying that the addition of Spirulina did not significantly alter the volumetric mass characteristics of the analog rice granules. According to Lee *et al.* (2022), a higher bulk density indicates a more compact rice texture. In terms of color brightness, the values decreased in the order of 0% until 4.5% spirulina. As the concentration of Spirulina increased, the brightness value tended to decrease.

In terms of color parameters, a significant reduction in *L* values was observed with increasing spirulina concentration, from 76.00 (0% spirulina) to 28.08 (4.5% spirulina), reflecting a notable darkening of the product due to the presence of natural pigments such as phycocyanin.

The *a** values shifted from slightly negative in 0% spirulina to more pronounced green hues in 3% spirulina (–4.13), while *b** values, representing yellowness, increased from 4.39 (0% spirulina) to a peak at 19.32 (3% spirulina), then slightly declined in 4.5% spirulina. According to Su *et al.* (2023), increasing the concentration of *S. platensis* resulted in a more intense green color. This is due to the pigment content in *S. platensis*, which has a polar bond with water, producing a deeper green hue.

Phytochemical Profile of Porang Analog Rice with Spirulina

The compounds tested included alkaloids, saponins, terpenoids, flavonoids,

Table 4 Comparison of chemical profiles in *S. platensis*, uncooked porang analog rice spirulina 1,5%, and cooked porang analog rice with spirulina 1.5%

Compound	*S. platensis*	Uncooked porang analog rice with spirulina 1,5%	Cooked porang rice with spirulina 1,5%
Alkaloid	+	-	-
Flavonoid	+	+	+
Phenol	+	+	+
Saponin	+	+	+
Terpenoid	-	-	-
Steroid	+	-	-

(+) = identified, (-) = not identified

phenols, and steroids. The results of the phytochemical screening of *S. platensis*, the selected uncooked porang analog rice with spirulina 1,5%, and cooked porang analog rice with 1,5% are presented in Table 4.

Phytochemical screening of *S. platensis* indicated the presence of alkaloids, as evidenced by the formation of yellow to brownish precipitates. The phytochemical test for flavonoid compounds showed positive results in *S. platensis*, uncooked porang analog rice spirulina 1,5%, and cooked porang analog rice spirulina 1,5%, indicated by the formation of reddish to orange coloration upon reaction. The phenolic test also showed positive results for all samples, indicated by the appearance of a bluish-black color.

This color results from the reaction between Fe^{3+} and phenolic compounds present in the extract. This finding aligns with that of Uzlasir *et al.* (2023), who stated that *S. platensis* contains phenols, as indicated by the color change upon the addition of $FeCl_3$ due to the presence of hydroxyl groups. The saponin test showed positive results, with stable foam formation lasting for 10 min in all samples. The steroid test showed a positive result for *S. platensis*, whereas uncooked porang analog rice and cooked porang analog rice spirulina did not contain steroids.

Similarly, alkaloids were detected only in *S. platensis,* but not in the rice samples. The disappearance of alkaloids and steroids after processing may be attributed to their thermal instability, as these compounds are susceptible to degradation, oxidation, and structural modification during cooking (Casado *et al.* 2023). In addition, interactions with proteins, glucomannan from porang, or lipids in the rice matrix may cause binding or masking effects, while the relatively low Spirulina concentration (1.5%) could further dilute these compounds below the detection threshold. Such reductions or losses of certain phytochemicals during processing are commonly observed in functional food products enriched with microalgae, highlighting the importance of optimizing processing conditions to preserve bioactive compounds.

Antioxidant Activity of Porang Analog Rice with Spirulina

The antioxidant capacities of *Spirulina platensis*, analog rice with 1.5% *Spirulina*, and its cooked form were evaluated based on their IC_{50} values, which reflect the concentration required to inhibit 50% of free radical activity. Thermal processing was found to enhance antioxidant potential, as evidenced by the decreased IC_{50} values observed in the cooked sample.The IC_{50} values of the samples are presented in Table 5.

Statistical analysis using one-way ANOVA revealed a significant difference ($p < 0.05$) in the IC_{50} values among *Spirulina platensis*, uncooked analog rice with 1.5% *Spirulina*, and the cooked analog rice spirulina 1.5%. Interestingly, the cooked analog rice exhibited the highest antioxidant activity, indicated by the lowest IC_{50} value (47.10 ± 9.04 ppm), which was significantly different from that of the other two samples.

Table 5 IC_{50} values of *S. platensis*, uncooked porang analog rice with spirulina 1,5%, and cooked porang analog rice with spirulina 1.5%

Samples	IC_{50} value (ppm)	Classification
Spirulina platensis	98.43±3.14[a]	Strong
Uncooked porang analog rice with spirulina 1,5%	70.97±2.89[ab]	Strong
Cooked porang analog rice with spirulina 1,5%	47.10±9.04[b]	Very strong

According to Blois (2005), a compound is considered a very strong antioxidant if its IC_{50} value is below 50 ppm, strong (50–100 ppm), moderate (101–150 ppm), and weak (151–200 ppm). Hydrothermal treatment likely enhanced the liberation of these bioactives and potentially produced novel antioxidant peptides or compounds. This effect can be explained by the breakdown of complex proteins and polysaccharides into smaller, more bioavailable molecules during cooking, which not only liberates bound phenolics but may also generate bioactive peptides with radical-scavenging activity. Recent studies by Masoumifeshani *et al.* (2025) on enzymatically hydrolyzed *Spirulina* proteins have shown remarkably low IC_{50} values (23–35 µg/mL), suggesting the substantial antioxidant potency of small peptide fractions. These findings align with our results, indicating that cooking may mimic hydrolysis by cleaving larger molecules into more active products. Similarly, Hussein *et al.* (2025) investigated the antioxidant activity of pasta enriched with *Spirulina platensis.* Their results showed that even after cooking, samples containing 10% Spirulina retained high antioxidant capacity, as reflected by a DPPH radical scavenging activity of 42.49 ± 0.15 µmol/g and a total phenolic content (TPC) of 2.95 ± 0.11 mg/g. These values fall within the upper range for functional food products and can be categorized as indicative of strong antioxidant activity, especially considering the thermal processing involved in their preparation.

The addition of *Spirulina platensis* to staple food products has been shown to enhance antioxidant activity. Koli et al. (2022) demonstrated that Spirulina-fortified green pasta showed a remarkable increase in TPC from 8.71 to 76.62 mg GAE/100 g after enrichment, with levels remaining high even after cooking (69.05 mg GAE/100 g). Antioxidant activity measured by DPPH and FRAP assays also increased significantly, with DPPH radical scavenging activity reaching 50.7% in pasta containing 15% Spirulina, despite thermal processing.

CONCLUSION

This study identified porang analog rice with 1.5% *Spirulina platensis* as the most preferred formulation based on hedonic testing. The addition of *S. platensis* affected the physical, nutritional, phytochemical, and antioxidant properties of the product. The selected formulation had acceptable cooking quality, good nutrient content, positive phytochemical results, and very strong antioxidant activity. These findings highlight the potential applications of these mushrooms in the functional food industry, particularly in diabetic-friendly diets and nutraceutical development. However, the limitations of this study include the relatively small sensory panel size and the absence of shelf-life stability and glycemic index evaluations, which warrant further investigation.

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