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Formulating Nutritious Wet Noodles with *Spirulina platensis*: Exploring Proximate Composition, Antioxidant Activity, and Consumer Preferences

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ABSTRACT: The incorporation of *Spirulina platensis* into food products has been extensively explored. In this study, wet noodles were enriched with *Spirulina platensis* at four different concentrations: 0% (P0), 1% (P1), 5% (P2) and 10% (P3). Sensory and hedonic evaluations, proximate composition and antioxidant properties were assessed. Overall, formulations P1 and P2 were significantly preferred ($p < 0.05$) in terms of appearance and aroma compared to the control (P0). Additionally, the texture and taste scores of spirulina-enriched wet noodles were higher ($p < 0.05$) than control. Among all treatments, P1 emerged as the most favourable formulation ($p < 0.05$) for aroma, texture, and taste in the hedonic test. Moreover, the *Spirulina platensis* supplementation had significant effect on the protein (11.62-18.46%) and fat content (0.57-0.83%) ($p < 0.05$) compared to the control noodles (9.73% and 0.24%). Furthermore, the antioxidant activity of the *Spirulina platensis* wet noodles increased in a dose dependent manner. The IC50 values for DPPH radical scavenging activity were 339.749 ppm (P0), 61.473 ppm (P1), 39.965 ppm (P2), and 27.439 ppm (P3), respectively. These results suggest that fortifying wet noodles with *Spirulina platensis* not only improves the sensory attributes but also enhances the nutritional quality and functional value.

Keywords: antioxidant; microalgae; nutritious food; *Spirulina platensis*; wet noodles

1. Introduction

Food diversification and enhancing the nutritional value of food products are strategic efforts to address the issues of malnutrition and global food security (Dewi et al., 2024; Dewi et al., 2024; Farida et al., 2023). Currently, food consumption in Indonesia heavily relies on staples such as wheat, corn, and rice (Wijayati et al., 2019). However, over-reliance on specific food sources can lead to nutritional imbalances in the population. In fact, Indonesia possesses abundant biological resources that can be utilized to produce food, medicines, and other products (Daryono & Hutasoit, 2024). Developing a broader range of nutrient-dense foods through diversified products is one way to address this challenge. Spirulina (*Arthrospira platensis*), a highly nutritious food source, serves as the basis for the development of popular foods such wet noodles in this study.

Spirulina platensis, a blue-green microalga, is recognized as a nutrient-dense food source and holds potential as a raw material for various food products (Ahda et al., 2024; Dewi et al., 2024). This *Cyanophyta* microalgae is well-known for having abundant nutritional content that includes proteins, vitamins, minerals, and bioactive substances (Mazareta et al., 2024). Dewajani et al., (2024) reported that bioactive compounds are able to reduce (ward off) 50% of free radicals. Other than that, *Spirulina platensis* contains high protein levels, constituting 50-70% of its dry weight, and is rich in essential amino acids such as phenylalanine, tyrosine, and tryptophan (El-Anany et al., 2023; Yuliani et al., 2020). Syaichurrozi et al., (2022, 2023) mentioned that twenty times as much protein is found in one hectare of *Spirulina platensis* biomass as in one hectare of corn or soybeans. *Spirulina platensis* is also a good source of important minerals, including iron, calcium, magnesium, and phosphorus, as well as vitamins such as A, B1 (thiamine), B2 (riboflavin), B3 (niacin), B6 (pyridoxine), and B12 (cyanocobalamin) (Dewi et al., 2024; Grosshagauer et al., 2020). Additionally, *Spirulina platensis* contains several antioxidants, notably phycocyanin, which can

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protect the body from oxidative stress and inflammation (Andrade, 2018; Bortolini et al., 2022).

Spirulina platensis has been widely studied as an ingredient in various food products, for instance beverages (Aleksandrovna et al., 2019), bread (Hernández-López et al., 2023), biscuits (Silva et al., 2021), and dietary supplements (Paraskevopoulou et al., 2024). In this study, *Spirulina platensis* was incorporated into wet noodles, a popular food in many Asian countries, including Indonesia, due to their versatility and chewy texture. However, traditional wheat flour noodles typically contain only 8–10% protein (Ntau et al., 2022), and are not considered an optimal source of protein due to their unbalanced amino acid profile (Maemunah et al., 2022). Therefore, developing spirulina-based wet noodles is a strategic and relevant innovation in creating more nutrient-dense food options. Moreover, *Spirulina platensis* offers benefits for sustainable production. It can be cultivated in both freshwater and saltwater and even in extreme condition such as wastewater (Putri et al., 2023; Putri et al., 2023). They also grow rapidly in conditions that do not require large tracts of land, making it an environmentally friendly and sustainable protein source compared to traditional crops and animal proteins, which require more natural resources like water and land for agriculture (Dewi et al., 2022; Pradana et al., 2020).

Despite these advantages, there are challenges in developing spirulina-based noodle products, particularly in terms of consumer acceptance. One of the major challenges is the strong flavour and colour of *Spirulina platensis*, which may reduce the product's appeal. In large quantities, the distinctive bluish-green colour of *Spirulina platensis* can be off-putting to some consumers, and its unique "grassy" or "algal" flavour may affect the product's sensory perception. Therefore, sensory, and hedonic testing is essential to ensure consumer acceptance of spirulina-based wet noodles. Other than that, *Spirulina platensis*, being rich in bioactive compounds, introduces challenges such as ensuring its even distribution within the noodle matrix and preventing degradation of sensitive nutrients during processing. Hence, an appropriate method, particularly in the diffusion of water and nutrients during dough preparation is essential. This ensures that the bioavailability of *Spirulina platensis's* nutrients is preserved while achieving uniform texture and colour, contributing to the product's overall acceptance. On account of this, this study aims to develop spirulina-enriched wet noodles by evaluating their nutritional content through proximate and antioxidant analysis, and assessing consumer acceptance through sensory and hedonic evaluations.

2. Materials and Methods

2.1. Time and Location

This study was conducted over a six-month period, from March to September 2024. The process of producing *Spirulina platensis* wet noodles—from dough mixing through sensory, hedonic, and DPPH analysis—took place at the Marine Product Processing Teaching Factory (TEFA) in Marine and Fisheries Polytechnic of Jembrana. Proximate analyses were performed at the Banyuwangi Marine and Fisheries Product Quality Testing and Development Unit.

2.2. Materials

The materials used in this study included wheat flour (Bogasari), eggs (Pasar Negara), RO water (Pasar Negara), salt (Dolphin), tapioca flour (Rose Brand), *Spirulina platensis* powder (Herbalist), sensory and hedonic test sheets, distilled water (ROFA), nitrogen-free paper (Koreclab), sulfuric acid (Smart-Lab, p.a), peroxide acid (Smart-Lab, p.a), sodium hydroxide (Merck, p.a), hydrochloric acid (Merck, p.a), boric acid (Merck, p.a), chloroform (Supelco, p.a) and methanol (Merck, p.a). The tools used include spoons, basins, rolling pins, dough mats, knives, stoves (Rinai), pans (Maspion), porcelain cups, crucibles, vortex mixers, measuring cylinder (Iwaki), beakers (Iwaki), analytical scales (Osuka), distillation flasks (Pyrex), soxhlet (Pyrex), ovens (Memmert), furnaces (Saftherm), desiccators (Duran), test tubes (Pyrex) and spectrophotometer UV-Vis UV752N.

2.3 Methods

2.3.1. *Spirulina platensis*-Based Wet Noodles Formulation

The production of *Spirulina platensis* wet noodles followed the guidelines in SNI 2987:2015 on Wet Noodles, with some modifications (BSN, 2015). *Spirulina platensis* powder used in this experiment was 85 mesh in size with a protein content of 65% and fiber of 12%. Meanwhile, the temperature and humidity during dough preparation were run at 18-24°C and 40-60% ensuring a consistent texture while retaining *Spirulina platensis*'s nutritional integrity. Appropriate conditions allow for optimal gluten development that gives dough its elasticity and structure leading to even colour distribution without decreasing its bioactivity compounds. The process began with preparing raw materials, including wheat flour, eggs, water, salt, and *Spirulina platensis*. The specific formulation is detailed in Table 1.

Tabel 1. *Spirulina platensis* Wet Noodles Formulation

Raw Materials	Unit	Control (P0)	F 1 (P1)	F 2 (P2)	F 3 (P3)
Wheat flour	g	250	247.5	237.5	225
Egg	egg	1	1	1	1
Salt	g	1	1	1	1
Water	ml	50	50	50	50
*Spirulina platensis**	g	0	2.5	12.5	25

Note: **Spirulina platensis* concentration: 1, 5, 10% from the weight of wheat flour. F1 is formulation 1, F2 is formulation 2, F3 is formulation 3

Next, *Spirulina platensis*, eggs, wheat flour, and salt were combined to form a dough, which was thoroughly mixed by gradually adding water. The dough was left to rest

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in a covered container for 15 minutes, allowing it to smooth out. Tapioca flour was then added, giving the dough a smooth, glossy, and slightly dense texture that was easy to roll. The dough was rolled to a thickness of 2 mm and cut into 20 x 20 cm sheets. These sheets were then sliced into noodle shapes. Proximate and antioxidant analyses were performed on the finished noodles. For sensory and hedonic testing, other noodle samples were boiled for five minutes. The sensory and hedonic tests evaluated consumer preferences and assessed the flavour, scent, texture, and appearance of the noodles.

2.3.2. Sensory and Hedonic Analysis

Sensory and hedonic evaluations of the *Spirulina platensis* wet noodles were conducted according to SNI 2987:2015 for Wet Noodles and SNI-01-2346-2011 for Sensory Testing Standards of Fisheries Products (BSN, 2015; BSN, 2011). Thirty untrained panellists (12 men and 18 women, aged 18-40) participated in the evaluation. Four noodle samples (P0, P1, P2, and P3) were assessed based on appearance, texture, taste, and aroma. Panellists rated their preference for each sample using a scale from 1 to 9, where 9 represented the highest rating. Equation (1) was used to calculate the sensory and hedonic scores:

$$P\left(\bar{x} - \left(1.96 \cdot \frac{s}{\sqrt{n}}\right)\right) \leq \mu \leq \left(\bar{x} + \left(1.96 \cdot \frac{s}{\sqrt{n}}\right)\right) \cong 95\% \quad \textbf{(1)}$$

where P is the sensory/hedonic value, $\bar{x}$ is the mean value of each attribute, s is the standard deviation of food quality and n is the number of panellists.

2.3.3. Proximate Analysis

Proximate analysis of *Spirulina platensis* wet noodles followed these standards: SNI 2354.2:2015 for Water Content, SNI 2354.1:2010 for Ash Content, SNI 2354.3:2017 for Fat Content, and SNI 01-2354.4:2006 for Protein Content (BSN, 2015, 2010, 2017, 2006). Each test was performed in duplicate.

To determine water content, 5 grams of the sample were placed in a dried porcelain cup and heated at 105°C for 16 hours. After cooling, the sample was placed in a desiccator until a consistent weight was achieved. The water content was calculated using Equation (2).

$$Water\ Content\ (\%) = \frac{B-C}{B-A} x100\% \quad \textbf{(2)}$$

where A is the weight of the empty cup, B is the weight of the cup with the wet sample and C is the weight of the cup with the dried sample.

For ash content analysis, 5 grams of the sample were dried at 105°C for sixteen hours to remove water content. After cooling, the sample was put in a desiccator to eliminate any last traces of water. Subsequently, the sample was burned for eight hours at 550°C in a furnace until all the organic material was gone and no more smoke was released. The sample was then chilled until it reached a steady weight. Equation (3) was used to compute the ash content.

$$Ash\ Content\ (\%) = \frac{B-A}{C} x100\% \quad \textbf{(3)}$$

where A is the weight of the empty crucible, B is the weight of the crucible with ash and C is the weight of initial sample.

The nitrogen content was multiplied by 6.25 to get the protein content. A 0.3 g sample was heated to 410ºC for 2 hours, with the addition of 15 ml of 97% concentrated sulfuric acid and 3 ml of 30% hydrogen peroxide to create ammonium sulphate, to extract nitrogen compounds. After then, ammonium sulphate and sodium hydroxide were combined to create ammonium hydroxide. Ammonium hydroxide was separated via distillation to remove the ammonia component. Finally, boric acid bonded ammonia to form ammonium borate, which hydrochloric acid was used to titrate. Using equation (4), the crude protein concentration was determined stoichiometrically.

$$Protein\ Content\ (\%) = \frac{(V_A-V_B)\ x\ N_{HCl}\ x\ 14.007\ x\ 6.25}{W\ x\ 1000} x100\% \quad \textbf{(4)}$$

where V_A is the volume (ml) of sample titration, V_B is the volume (ml) of blank titration, N is the normality of HCl standard, W is the sample weight (g), 14.007 and 6.25 are the atomic weight of nitrogen and the protein conversion factor.

In order to extract the lipid content, two g of the sample were mixed with 1:12 v/v methanol and chloroform solvents for 10 minutes at 5,000 rpm. After that, 10 ml of chloroform was added, and the mixture was homogenized again for 30 seconds at 5,000 rpm. After filtering, the homogenate was distilled for one to three hours at a temperature between 50 and 70°C, and until a constant lipid weight was reached. Equation (5) was used to calculate the percentage of fat content.

$$Fat\ Content\ (\%) = \frac{C-A}{B} x100\% \quad \textbf{(5)}$$

where A is the weight of the empty cup, B is the weight of the sample, and C is the final weight of the cup and extracted sample.

2.3.4. DPPH Analysis

The DPPH analysis was conducted to determine the antioxidant capacity of various substances using 2,2-diphenyl-1-picrylhydrazyl (DPPH) solution. The analysis towards spirulina-based wet noodles was in accordance with Dewajani et al., (2024); Hansen & Sutriningsih, (2018). A DPPH solution with a concentration of 40 ppm was produced by weighing 10 mg of DPPH solids and dissolving it in 250 ml of 80% ethanol. 3 ml of DPPH solution and 3 ml of 80% ethanol were combined to create the blank solution.

10 millilitres of ethanol were used to dissolve 0.1 grams of sample, which results in a sample solution containing 100,000 ppm. Subsequently, the sample solution was diluted at 1, 10, 100, 1,000, and 10,000 ppm. Then, 3 ml of each diluted solution was taken and added to a dark bottle along with 3 ml of DPPH solution. After that, the solution was left for 15 to 20 minutes until the colour turned yellow

instead of purple. The solution was then tested for absorbance at a wavelength of 515 nm using a UV-Vis spectrophotometer. Eventually, the percentage inhibition that antioxidants can capture free radicals is expressed in Equation 6. Whilst, the equation of linear regression derived from the association between concentration of solution and percentage inhibition was used to determine the Inhibitory Concentration 50% (IC50) value representing the concentration of a sample required to inhibit 50% of the DPPH radicals.

$$\% \, Inhibition = \frac{A_0 - A_1}{A_0} x100\% \tag{6}$$

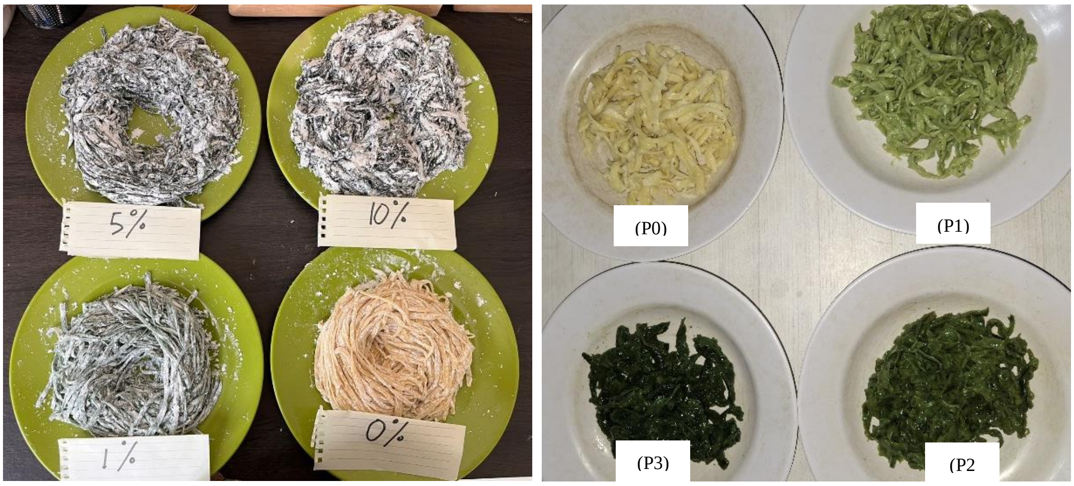
where A_0 is the blank absorbance and A_1 is the sample absorbance.

2.4. Data Analysis

Data were statistically analysed using IBM SPSS Statistics 26, with a One-Way ANOVA at a 95% confidence level. The Tukey Test was also employed to determine significant differences between treatments.

3. Results and Discussion

Figures 1 (a) and (b) show the visual observation results, which indicate that adding *Spirulina platensis* to wet noodles significantly affects the final colour appearance of product. Compared to the control (0%) and 1% *Spirulina platensis*, wet noodles with 5% and 10% *Spirulina platensis* exhibit a more vibrant green hue and a more brittle shape. This demonstrates that *Spirulina platensis* has been successful in giving wet noodles a naturally occurring colour. *Spirulina platensis* can also alter the texture of wet noodles in addition to their colour. It is evident from the result that noodles with high concentrations of *Spirulina platensis* tend to be softer and lack the uniformity of a clean noodle sheet shape.



(a) (b)

Figure 1. (a) *Spirulina platensis* Wet Noodles Before Boiling; (b) *Spirulina platensis* Wet Noodles After Boiling

This visual observation is consistent with earlier research that demonstrated *Spirulina platensis* may be used to naturally colour a variety of foods, including noodles (Christwardana et al., 2023; Hernández-López et al., 2023). Due to its high pigment content, *Spirulina platensis* can enhance food products' nutritional value in addition to adding eye-catching hues. As a result, consumers who are concerned about their health may find that wet noodles enhanced with *Spirulina platensis* are a desirable functional food option.

3.1. Effect of *Spirulina platensis* Concentration on the Sensory Result of Wet Noodles

According to El-Anany et al., (2023); Utari et al., (2023), sensory analysis is a technique employed using the five senses human to evaluate the qualities of food such as taste, aroma, texture, appearance, and overall look. The findings of this experiment can be utilized to assist producers in developing areas in which the current product need to be improved and develop new food with features that consumers will find appealing. As seen in Figure 2, sensory analysis was carried out to determine key characteristics of *Spirulina platensis* wet noodle products.

The addition of *Spirulina platensis* to wet noodles affects panellist preferences for appearance attributes ($p < 0.05$), aroma ($p < 0.05$), texture ($p > 0.05$), and taste ($p > 0.05$) as displayed in Figure 3. *Spirulina platensis* generally has the tendency to lower the average value of the texture and taste qualities while increasing the average value of the appearance and aroma attributes. Wet noodles can have a more appealing hue when *Spirulina platensis* is added at a specific concentration, as shown by the treatments P1 and P2 which had the highest average values for the appearance (7.90 and 8.14) and aroma (8.02 and 7.51). This suggests that *Spirulina platensis* can give food products a naturally occurring green hue with a smoother surface. However, the addition of 10% *Spirulina platensis* tended to produce low appearance and aroma sensory values, namely 6.10 and 5.82

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(p < 0.05). On the other hand, texture and taste characteristics were adversely affected by the inclusion of *Spirulina platensis*. The average values of both criteria exhibited a tendency to decline as the concentration of *Spirulina platensis* increased. This suggests that adding too much *Spirulina platensis* to wet noodles may alter their flavour and texture, making the panellists less fond of them. This is probably because the addition of *Spirulina platensis* altered the physicochemical characteristics of the noodle dough, causing changes in pH or viscosity.

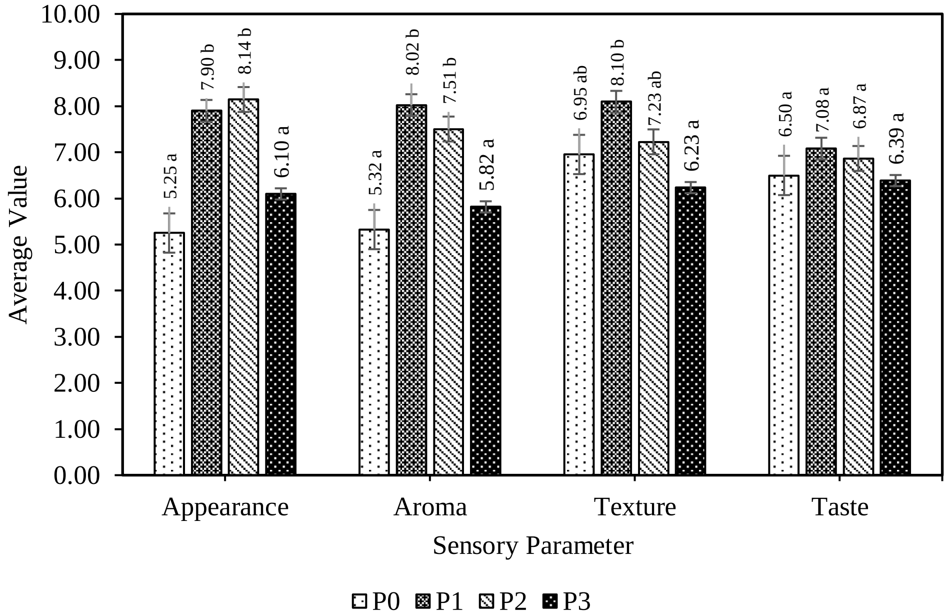

Figure 2. Sensory Results of *Spirulina platensis* Wet Noodles.
The results are the average values (n = 30). Different letter notations indicate significant different (p < 0.05)

Given that appearance is the first feature that consumers consider before choosing to try a product, appearance is one of the crucial factors evaluated using the five senses of sight (Ersyah et al., 2022). When it comes to appearance, the proper concentration of *Spirulina platensis* (1 and 5%) produces excellent evaluation results with smooth surface characteristics, consistent size, and the characteristic bright green colour of *Spirulina platensis*. A 10% concentration, on the other hand, resulted in a low evaluation value due to the excessively thick green colour, uneven noodle shape. The presence of phycobilin pigments, specifically phycocyanin and phycoerythrin, in wet noodles reinforced with *Spirulina platensis* may account for the variation in colour (Bortolini et al., 2022). Wang et al., (2023) reported that the concentration of *Spirulina platensis* phycobilin is 20% per g of dry biomass weight, with phycocyanin contributing a blue-green hue and phycoerythrin a red one. The unique green colour of the wet noodles is caused by the predominance of phycocyanin in the *Spirulina platensis*. More phycobilin pigments are also attached to the protein matrix of the noodles. Hence, the noodles lose some of their neatness and uniformity in size. The reason for this is that compared to wheat flour, *Spirulina platensis* particles are often finer in size. These tiny particles have a greater capacity to absorb water, which makes the dough more viscous and challenging to knead (Seghiri et al., 2019).

One of the primary elements influencing how well a product is perceived by customers is its aroma. According to Zen et al., (2020), products that have a pleasing aroma likely to pique consumers' interest and encourage them to purchase the product. Additionally, a product's scent can give away information about its overall quality. When noodles infused with *Spirulina platensis*, their aroma takes on unique qualities like seaweed or algae, earthy, woody, and fishy notes. The formation of amines (trimethylamine) and sulphides (dimethyl sulphide), which give microalgae an unpleasant smell, is frequently the source of fishy odor (Coleman et al., 2022; Urlass et al., 2023). Jia et al., (2024) mentioned that additional chemical components like alcohols, terpenoids, ketones, and aldehydes also contribute to this scent. At low levels, these compounds may be masked or diluted within the noodle matrix, but at higher concentrations, their intensity becomes overwhelming, negatively impacting the aroma. The threshold concentration for human detection of these odours is exceeded, resulting in sensory rejection by consumers. Additionally, *Spirulina platensis* is rich in polyunsaturated fatty acids (PUFAs), which are prone to oxidative degradation during processing and storage (Boutin et al., 2019). The oxidation of PUFAs generates secondary products like malondialdehyde and volatile aldehydes, which impart rancid or off-flavours (Boutin et al., 2019). High levels of *Spirulina platensis* amplify the concentration of these oxidation products, further degrading the flavours and aroma of the noodles. Therefore, heat or shear during dough preparation can accelerate lipid oxidation. The aroma attribute receives the highest rating when 1% *Spirulina platensis* was added, yet customers still find it acceptable because the aroma was not overly strong or fishy. On the other hand, the scent attribute value was prone to decline above 1% of additional concentration. Compared to other foods with a strong aroma or those with the addition of many spices and herbs, like chocolate cake, tempeh chips, and so on, the aroma of *Spirulina platensis* may be more prominent in mildly flavoured dishes or those without the addition of many spices and flavours, like wet noodles.

Texture describes the tangible qualities of a substance that are perceived and assessed by the touch, particularly when the substance is in contact with the mouth. Texture sense encompasses a number of different qualities, including smoothness, elasticity, dryness, and hardness. Texture is the outcome of a multifaceted interplay between the mechanical characteristics of food ingredients, oral physiology, and personal sensory perception (Junianto, 2022; Utari et al., 2023). In comparison to the control, the texture assessment of the noodle dough improved with the addition of *Spirulina platensis* at certain level. On the other hand, the sensory value dropped as the *Spirulina platensis* concentration reached 10% where the noodles were far more brittle and challenging to form. Meanwhile, noodles in the control group and those that had 1 or 5% *Spirulina platensis* were chewier, softer, smoother, and more compact. The texture and form of food are significantly influenced by water. Insufficient water in the dough will prevent gluten from forming, giving the finished product a delicate feel. Since *Spirulina platensis* has fine particles that easily absorb water, combining it with wheat flour becomes challenging because the dough becomes more viscous. Furthermore, the protein found in *Spirulina platensis* differs structurally from that found in wheat flour (Hernández-López et al., 2023). Water activates the gluten proteins in the dough, primarily glutenin and gliadin. This mass transfer leads to the formation of gluten strands, creating a network that gives the dough its elasticity and structure. When *Spirulina platensis* is added in high amounts, its high protein content and insoluble fibers interfere with gluten formation. *Spirulina platensis* particles compete with gluten proteins for water, which limits the hydration and bonding of gluten molecules. As a result, the gluten network becomes weaker, reducing its ability to provide elasticity and structure, leading to a more delicate and fragile texture. The interactions between these two proteins were unable to generate gluten as effectively as the interactions between wheat proteins do. Gluten is a network of proteins that gives dough its elasticity and stiffness. A poor gluten formation will make the dough more malleable and challenging to shape.

Taste is a multifaceted sense that is produced when water-soluble substances activate taste receptors on the tongue. The taste perception combines the senses of aroma and taste, which work together to create a fully immersive taste experience. *Spirulina platensis* added to wet noodles did not, on the whole, significantly improve the flavour characteristics ($p > 0.05$). The samples with the greatest taste scores were those enhanced with 1% and 5% *Spirulina platensis*. Taste has a major role in a product's acceptance. The flavour rating of wet noodle varied from 6.39 to 7.08 as opposed to the control, which came in at 6.50. Compared to the control, which is often bland, *Spirulina platensis* noodles at low concentrations have a unique algal taste leading to a better result. Nonetheless, the phycocyanin pigment produces somewhat bitter noodles at high concentrations (Hassanzadeh et al., 2022). Like many nutrient-dense meals, *Spirulina platensis* has a mildly bitter flavour. *Spirulina platensis* is naturally high in proteins and bioactive peptides, some of which have a bitter taste (Zeng et al., 2020). Excessive *Spirulina platensis* increases the concentration of these bitter compounds, making them more perceptible to the palate. As a result, adding *Spirulina platensis* requires either the proper concentration or enrichment with other ingredients that can contribute to the unique flavour of microalgae (Pratama et al., 2022).

3.2. Effect of *Spirulina platensis* Concentration on the Hedonic Result of Wet Noodles

Hedonic analysis is a technique that gauges how much a product is liked or disliked by customers. Participants in this test rate the product subjectively using their senses of taste, smell, and sight. Hedonic analysis is mostly used to assess the degree of liking for multiple identical products and ascertain the extent to which consumers accept a product. To put it another way, hedonic testing aids producers in comprehending how customers react to products from the standpoint of their preferences (Silva et al., 2021).

There are differences in consumer evaluations of each treatment (P0, P1, P2, and P3) based on the hedonic test results on *Spirulina platensis* wet noodles covering four parameters: appearance, aroma, texture, and taste as shown in Figure 3. In terms of appearance, treatment P2 had the greatest score (7.35) ($p < 0.0.5$), whereas treatment P0 (control) received the lowest average score (5.78). Compared to the control, P1 and P3, the addition of *Spirulina platensis* in P2 treatment had a good effect on appearance preferences, notably noodle colour. This could be because of the *Spirulina platensis*'s naturally occurring green tint, which is more appealing with a more uniform shape and smooth surface. Treatment P0 received a lower aroma parameter score than P2 and P1, but the difference was not statistically significant ($p > 0.05$). The average values for P1 and P2 were comparatively high, at 7.32 and 6.75. This indicates that consumers like an aroma that is somewhat provided by the inclusion of *Spirulina platensis*. On the other hand, treatment P3, which received a slightly lower score than P2, demonstrated that adding too much *Spirulina platensis* could start to lessen how appealing the product's scent is.

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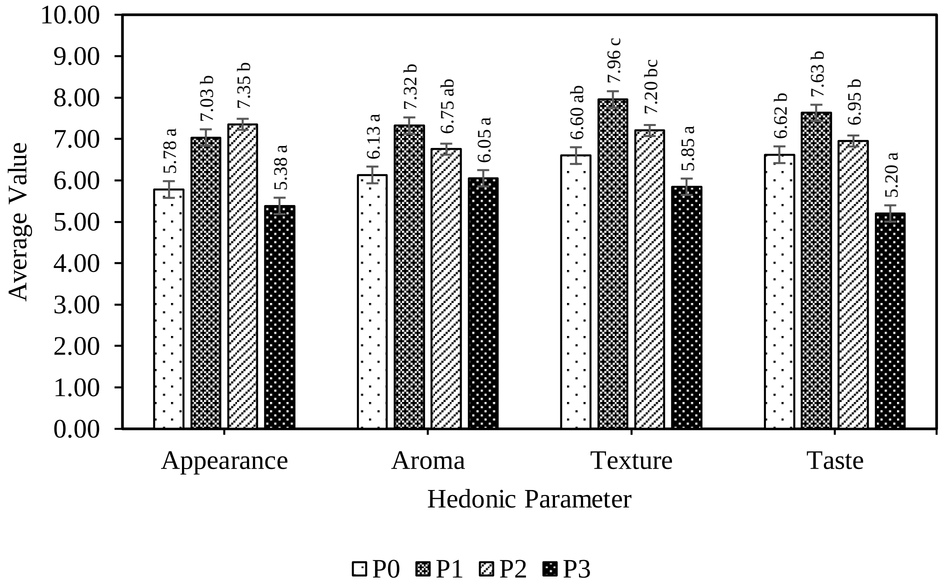

Figure 3. Hedonic Results of *Spirulina platensis* Wet Noodles.
The results are the average values (n = 30). Different letter notations indicate significant different ($p < 0.05$)

The highest average score of texture parameter (7.96) went to treatment P1, suggesting that customers prefer the texture of noodles with a moderate dose of *Spirulina platensis*. Noodle texture that is overly soft or hard can impair the appeal, and P1 could provide an appropriate balance. P0, the control, had a score of 7.20, whereas P2 and P3, which had higher concentrations of *Spirulina platensis*, received a score of 5.85. This demonstrates that the texture of wet noodles can be enhanced by adding a small amount of *Spirulina platensis*. P1 also received a pretty high score (7.63) for the final criteria, taste, which was not as high as the texture. Compared to P0, P2, or P3, customers prefer the flavour of noodles with a *Spirulina platensis* concentration in P1. The taste values of treatments P2 and P3 decreased to 6.95 and 5.20, respectively, which might have been brought on by the *Spirulina platensis*'s strong taste if administered in excess. Based on these four hedonic factors, P1 was found to be the most desired noodles overall.

Panellists favoured noodle products enhanced with 1% *Spirulina platensis*, with values ranging from 7.03 to 7.96 for all attributes assessed, according to the results of the hedonic test of *Spirulina platensis* wet noodles. The panellists' preferences, particularly with regard to the texture and taste criteria, were at the "like" level. Panellists rated the concentrations at 5% and 10% as "rather like to like" and "neutral to somewhat like," respectively. Consumers find large doses of *Spirulina platensis* less palatable due to the green colour that is too thick, the texture that can be brittle, and the strong flavour of algae. According to (Christwardana et al., 2023), the nutritional composition of food products, namely in the form of protein, pigments, and minerals, significantly impacts consumer preferences.

3.3. Effect of *Spirulina platensis* Concentration on the Proximate Result of Wet Noodles

Figure 4 presents the proximate analysis results for *Spirulina platensis* wet noodles across four different formulations: P0, P1, P2, and P3. The parameters measured include protein, lipid, water, and ash content, expressed as percentages. Noodles contain a lot of protein, second only to water. Among the macronutrients, protein is utilized as an energy source and is important in the synthesis of biomolecules (Andrade, 2018). According to the results, there is a statistically significant variation in the protein content. Specifically, P3 shows the highest protein content ($p < 0.05$), while the other formulations, P0, P1, and P2, show slightly lower protein contents, ranging around 9-12% ($p < 0.05$). As illustrated in Figure 4, the addition of *Spirulina platensis* enhanced the protein content of noodles by 11.62 ± 0.06% for 1%, 12.46 ± 0.03% for 5%, and 18.46 ± 0.16% % for 10% of the sample. The proximate result showed that the increase in *Spirulina platensis* concentration was directly related to the high protein content. Christwardana et al., (2023) mentioned that the amount of protein acquired in food increases with the amount of *Spirulina platensis* supplied. Nonetheless, the protein content of control noodles was 9.73 ± 0.32% prior to the addition of *Spirulina platensis*. Hence, higher protein noodles can be produced by increasing the amount of *Spirulina platensis* since it fairly consists of 60-70% of protein (El-Anany et al., 2023). Meanwhile, protein content in wheat flour is 8-20% (Žilić et al., 2011), which is less than that of *Spirulina platensis*. Unlike the protein in wheat (gluten), which operates to generate a gel that makes dough tough, the protein in *Spirulina platensis* is good for the body, acts as a structural element, and improves the nutritious value of meals (Silva et al., 2021).

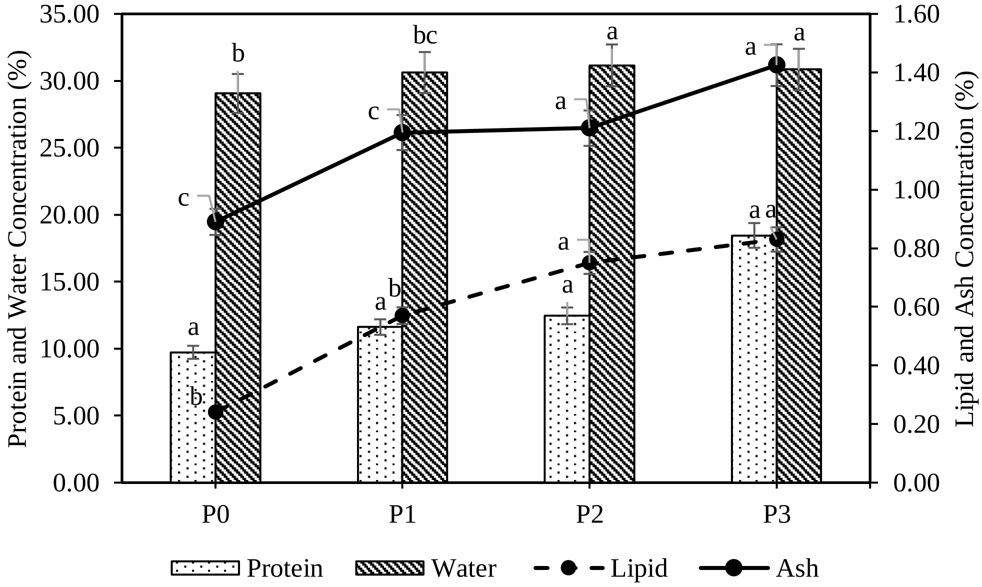

Figure 4. Proximate Results of *Spirulina platensis* Wet Noodles.

The results are the average values (n = 2). Different letter notations indicate significant different at the same proximate content ($p < 0.05$)

The proteins in *Spirulina platensis* also include essential amino acids, which complement the lower protein content of wheat flour, contributing to the observed increase in protein levels. The linear correlation between *Spirulina platensis* concentration and protein content is supported by proximate analyses, which confirm that the protein increment is proportional to the added *Spirulina platensis* mass (El-Anany et al., 2023). Noodles must have a minimum protein level of 9%, but *Spirulina platensis* can increase protein content in noodles to as much as 11.62-18.46% in SNI 2987:2015 (BSN, 2015). Consequently, *Spirulina platensis* wet noodles' protein content satisfies the standard.

For the lipid content, there is a much lower percentage across all formulations compared to protein and water which was below 1% ($p > 0.05$). P0 and P1 have slightly higher lipid content accounting for 0.24 ± 0.06% and 0.57 ± 0.04% compared to P2 and P3 namely 0.75 ± 0.02% and 0.83 ± 0.04%. The low lipid content might indicate that *Spirulina platensis* wet noodles are a low-fat product, aligning with the known nutritional profile of *Spirulina platensis*, which is typically high in protein but low in lipids (Seghiri et al., 2019). Cardoso et al., (2022) reported that *Spirulina platensis* only contains 3-5% of lipid including polyunsaturated fatty acids (PUFAs) like omega-3 and omega-6 fatty acids. Whereas, lipid content in wheat flour is 2.0–2.5%, which is less than *Spirulina platensis* (Devi et al., 2020). Since *Spirulina platensis* has a higher lipid content than wheat flour but is still considered a low-fat source, the fat content of the noodles increased slightly by 0.57 to 0.83%. Additionally, the hydrophobic nature of some *Spirulina platensis* lipids may enhance lipid retention during dough preparation and cooking processes, slightly increasing the overall fat content in the noodles. The result indicated that the lipid is very low when compared to meat and other high-fat foods (Sari et al., 2022), therefore, *Spirulina platensis*-infused low-fat noodles are a nutrient-dense food choice.

Water content is notably high across all formulations, with each exceeding 25% and showing no significant difference between formulations ($p > 0.05$). P1, P2 and P3 had a greater water content compared to P0, suggesting that the higher *Spirulina platensis* concentration, the higher the water content. Wet noodles are known for their high-water content, which may affect their mouthfeel and texture, giving them a more brittle texture as shown in Figure 2. The large mass addition of *Spirulina platensis* is directly associated with the increasing water content of noodles. Prior to *Spirulina platensis* being added, the noodles had 29.06 ± 0.49% water. Although *Spirulina platensis* has a low water content of less than 10%, it can react with water due to its hygroscopic and non-polar properties, which increases the water content of noodles when coupled with *Spirulina platensis* (Christwardana et al., 2023). Ahnan-Winarno et al., (2021) mentioned that a food's ability to withstand microbial attack is influenced by its water content. Food that contains less water have a longer shelf life than those that contain a lot of water. SNI 8217-2015 reported that the maximum water content for wet noodles is 35%. Meanwhile, the range for noodles containing *Spirulina platensis* is around 30.62-31.35%, which is satisfied the standard.

Ash content, which represents the mineral content, is also very low across all formulations, all falling below 1%,

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and there are no significant differences between them ($p > 0.05$). The lack of significant variation implies that mineral content is stable regardless of the formulation. This stability in ash content suggests that the primary nutritional differences between these *Spirulina platensis* noodles are likely due to variations in protein and, to a lesser extent, lipid content, rather than minerals. Ash content is often used to estimate the total mineral content, which is generally consistent with the expected composition of *Spirulina platensis* (Dewi et al., 2024). When more *Spirulina platensis* is introduced during the manufacturing process, the ash content of the noodles rises. This is because *Spirulina platensis* is an excellent source of minerals such as calcium, magnesium, iron, and phosphorus. *Spirulina platensis* contains a wide range of nutrients. Iron, calcium, and phosphorus are present in *Spirulina platensis* (Anvar & Nowruzi, 2021).

3.4. Effect of *Spirulina platensis* Concentration on the Antioxidant Activity of Wet Noodles

The antioxidant activity of spirulina-enriched wet noodles was assessed, as listed in Table 2. The IC50 value represents the concentration of a substance required to inhibit 50% of free radical activity in a DPPH assay. The IC50 value for the DPPH radical scavenging in the control noodle (0% *Spirulina platensis*) was 339.749 ppm, while the values for noodles containing 1%, 5% and 10% *Spirulina platensis* were 61.473 ppm, 39.965 ppm and 27.439 ppm, respectively. These results indicate that the *Spirulina platensis* supplementation enhanced the antioxidant properties of the wet noodles. A lower IC50 value indicates higher antioxidant potency. *Spirulina platensis* is rich in bioactive compounds with strong antioxidant activity, such as phycocyanin, carotenoids, polyphenols, and tocopherols (El-Anany et al., 2023; Yuliani et al., 2020). These compounds scavenge free radicals by donating electrons or hydrogen atoms, effectively neutralizing oxidative agents. When more *Spirulina platensis* is added to the dough, the concentration of these antioxidants in the noodles increases, resulting in a lower IC50 value. A study by (Fradinho et al., 2020) reported that the supplementation of 3% *Spirulina platensis* biomass in pasta significantly increased its antioxidant capacity, ranging from 67.97 ± 1.30% to 70.33 ± 4.36%. Similarly, Muresan et al., (2016) observed a nearly fourfold increase in DPPH scavenging activity when pasta was enriched with 5% *Spirulina platensis* compared to the control.

These findings suggest that the improvement in the antioxidant properties of spirulina-enriched wet noodles depends on the concentration of *Spirulina platensis* added to the dough. Previous reviews by (Asghari et al., 2016; Ravi et al., 2010) highlighted that *Spirulina platensis* exhibits strong antioxidant potential due to its bioactive compounds, including carotenoids, chlorophyll, and phycocyanin. Thus, spirulina-based wet noodles have the potential to serve as a functional food with enhanced nutritional value.

Table 2. Antioxidant Activity of *Spirulina platensis* Wet Noodles

Concentration (ppm)	Sample Absorbance	Inhibition (%)	IC50 (ppm)
P0			
100000	0.174	76.984	339.749
10000	0.195	74.206	
1000	0.317	58.069	
100	0.402	46.825	
10	0.535	29.233	
1	0.664	12.169	
P1			
100000	0.078	89.683	61.473
10000	0.152	79.894	
1000	0.198	73.810	
100	0.315	58.333	
10	0.491	35.053	
1	0.586	22.487	
P2			
100000	0.071	90.608	39.965
10000	0.15	80.159	
1000	0.191	74.735	
100	0.289	61.772	
10	0.455	39.815	
1	0.571	24.471	
P3			
100000	0.07	90.741	27.439
10000	0.094	87.566	
1000	0.185	75.529	
100	0.279	63.095	
10	0.436	42.328	
1	0.557	26.323	

4. Conclusions

The findings demonstrate that the supplementation of *Spirulina platensis* into wet noodles improved both sensory and nutritional properties. Wet noodles with 1% (P1) and 5% (P2) *Spirulina platensis* concentrations were preferred for the sensory properties. Notably, the 1% *Spirulina platensis* formulation (P1) emerged as the most preferred in terms of aroma, texture, and taste based on hedonic analysis. *Spirulina platensis* added into wet noodles formulation also improved the nutritional composition, especially by increasing protein and fat content. The addition of *Spirulina platensis* into wet noodles formulation also enhanced the antioxidant activity, as reflected by a decrease in IC50 values with higher *Spirulina platensis* concentrations. These results suggest that spirulina-enriched wet noodles offer the better sensory qualities and provide enhanced nutritional and functional benefits, positioning the *Spirulina platensis* wet noodles as promising and potential candidates for functional food development.

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Resti Nurmala Dewi: Writing – original draft, Visualization, Validation, Resources, Investigation, Formal analysis, Conceptualization. **Fenny Crista Anastasia Panjaitan:** Writing – original draft, Visualization, Validation, Investigation. **Sumartini:** Writing – original draft, Resources. **Nita Ariestiana Putri** Writing – original draft, Visualization, Validation.

Declaration of competing interest
The authors declare that none of the work reported in this study could have been influenced by any known competing financial interests or personal relationships.

Data availability
The data may be shared upon request.

Statement
The authors used ChatGPT 4 to proofread and enhance the English language while preparing this work. The writers took full responsibility for the publication's content after utilizing this tool/service, reviewing, and editing it as necessary.

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