Proximate composition, sensory evaluation, physical properties, mineral content and amino acid profile of nori-like product from Ulva lactuca and Gracilaria

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Research Article

Keywords: Ulva lactuca, Gracilaria, nori, sensory analysis

Posted Date: October 18th, 2023

DOI: https://doi.org/10.21203/rs.3.rs-3451985/v1

Additional Declarations: No competing interests reported.

Abstract

Nori is a dried edible seaweed sheet made from *Porphyra*, a genus of red algae that thrives primarily in subtropical waters. Nori-like products have been developed from tropical seaweed species, but they are still considered undesirable due to their astringent taste and lower protein content compared to the original nori. This investigation aimed to produce a nori-like product by utilizing a combination of locally sourced seaweeds *Ulva lactuca* and *Gracilaria* with the addition of anchovy flour to enhance its protein content. To obtain the optimal formulation of the product, we employed a design expert application to analyze sensory data collected from a hedonic scale assessment involving 25 trained panelists. We evaluated sensory characteristics, including appearance, aroma, texture, taste, and overall satisfaction. Additionally, we considered parameters such as crispness and color to determine the nori-like product quality. The best-selected product, determined through sensory evaluation, underwent further analysis of its proximate and amino acids profile, as well as mineral content. The results were compared to those of commercial nori from *Porphyra*. The highest-quality product was found to be the nori-like product with a formula consisting of 25.40% *Ulva lactuca*, 7.98% *Gracilaria*, 1.5% glycerol, and 4.12% anchovy.

Introduction

Nori is a customary cuisine made from red seaweed, commonly consumed following the drying or roasting process. It is usually made from the seaweed genus *Porphyra*. However, this species does not naturally grow in Indonesian waters. With the rising demand for nori in the country, efforts are being made to develop a nori-like product by substituting them with other abundant seaweed varieties that thrive in Indonesian waters (Valentine et al. 2020).

The demand for nori continues to surge globally, driven by its popularity as a healthy food ingredient. Numerous research studies have been conducted on the production of nori using locally sourced Indonesian seaweed., i.e. *Gracilaria, Ulva* and *Caulerpa* (Sinurat et al. 2022), *Gracilaria* (Rosida et al. 2021), *Ulva lactuca* and *Gelidium* (Erniati et al. 2018), *Gelidium* and *Eucheuma cottonii* (Abdulah et al. 2019), *Gracilaria* (Teddy 2009), *Porphyra marcossi* (Loupatty 2014), *Ulva lactuca* and *Eucheuma cottonii* (Zakaria et al. 2017). *Eucheuma cottonii* and *cassava leaf*(Aulia et al. 2021), *Ulva lactuca Linnaeus* and *Gracilaria* (Putri and Ningtyas 2017), *Hypnea saidana* (Lalopua 2018).

Gracilaria ais not commonly used in its raw state due to its slightly brownish color and presents challenges as it is not easily soluble in heat processing. However, it exhibits some elastic properties and can be easily molded (Rosida et al. 2021). This seaweed species holds significant economic importance in Indonesia, particularly for its role in agar-agar production (known as agarophytes), and it is extensively cultivated in the country due to its low maintenance requirements. This seaweed serves as a valuable industrial raw material that can also be utilized in the production of food items, such as nori (Yusuf et al. 2021).

On the other hand, green macroalgae *Ulva*, commonly known as sea lettuce, can be found in various intertidal zones along rocky or sandy coasts of oceans along most of Indonesia's coastlines. The green algae exist in different forms, including unicellular, colonial, and multicellular. *Ulva* is not only rich in carotenoids but also serves as a valuable source of vitamin B, proteins, and essential minerals such as calcium, potassium, magnesium, sodium, copper, iron, and iodine, in addition to dietary fibers. Nutrient-dense *Ulva lactuca* is frequently used in salads and kimchi preparations.

In Indonesia, nori is primarily in demand by restaurants serving Japanese, Korean, and Chinese cuisines, and it is typically imported directly from these countries of origin. Furthermore, nori products are also widely available in Indonesia as popular snacks, often imported from Korea, China, and Thailand. Given the abundant seaweed resources in Indonesia, which have not been fully utilized, there is a compelling need to explore the development of nori products using locally sourced seaweed.

The development of nori-like products using locally sourced Indonesian seaweed is anticipated to reduce the dependence on imported nori and boost the market value of Indonesian seaweed. Furthermore, these nori products have the potential to serve as an alternative source of healthy nutrition for the community, given their high fiber content and bioactive components, which confer various health benefits (Zakaria et al. 2017).

Investigations on nori-like products using locally sourced Indonesian seaweeds have been conducted (Sinurat et al. 2022). However, certain weaknesses were identified in the product, such as a bitter taste, firm texture, and lower protein content compared to commercial nori. The primary objective of this study is to develop a nori-like product by combining local seaweed *Ulva lactuca* and *Gracilaria*, enriched with anchovies to increase the protein content and achieve a product comparable to commercial nori.

Materials and Methods

Materials

Fresh *Ulva lactuca* was sourced from seaweed farms along the Takalar coastline in South Sulawesi, Indonesia. The collected seaweed was then sun-dried and carefully packaged before being transported to the laboratory in Jakarta. Dried *Gracilaria* was obtained from a local seaweed farmer in Brebes, Central Java, Indonesia. The seaweeds were rinsed and pre-treated with rice vinegar to eliminate any fishy odor (Keyimu 2014). Afterward, the seaweeds were thoroughly washed until reaching a neutral pH and stored in the refrigerator until they were ready for use. palm oil (Tropical), sesame oil (Lee Kum Kee), anchovies (Hays), oyster sauce (Lee Kum Kee), salt, glycerin, sodium metabisulfite, and water were purchased from a local market in Jakarta. These ingredients were used for seasoning during the processing. Additionally, commercial nori was also obtained from a local market and served as the control nori product.

Methods

Experimental Design

Nori was primarily prepared using *Ulva lactuca*, *Gracilaria*, and anchovies, following the procedures outlined by Sinurat et al. (2022) with some modifications, as depicted in Fig. 1. The experiment was designed to model and assess the effect of four independent variables on the response, aiming to optimize the nori-like product formulations. This was performed using a Mixture Design approach with 16 sets and 4 independent factors. Stat-Ease Design-Expert Software (Version 13.1.0.1, Stat-Ease, Inc., Minneapolis, MN 55413) was used for this purpose. The final nori-like product was influenced by four independent factors: A (*Ulva lactuca*), B (*Gracilaria*), C (Glycerin), and D (anchovy) in the formulations (Table 1).

Table 1
Optimization of Seaweed Formulation Using Design Expert 13® Program Preparation

Runs	**Ingredients (%)**			
	Ulva lactuca	***Gracilaria***	**Glycerin**	**Anchovy**
F1	24.7	6.6	2.7	5.0
F2	25.1	7.4	1.5	5.0
F3	24.4	8.0	2.2	4.4
F4	23.0	8.0	3.0	5.0
F5	26.0	6.0	3.0	4.0
F6	26.0	7.1	2.3	3.6
F7	25.4	8.0	2.6	3.0
F8	24.7	6.6	2.7	5.0
F9	26.0	8.0	1.5	3.5
F10	26.0	6.9	1.6	4.4
F11	26.0	7.1	2.3	3.6
F12	23.9	7.3	3.0	4.7
F13	24.4	8.0	2.2	4.4
F14	24.7	7.6	3.0	3.7
F15	26.0	6.0	2.0	5.0
F16	26.0	8.0	3.0	2.0

These factors were analyzed across different levels: *Ulva lactuca* (ranging from 23.0–26.0%), *Gracilaria* (ranging from 6.0–8.0%), glycerin (ranging from 1.5–3.0%), and anchovy (ranging from 2.0–5.0%). The variations in the quantities of these four factors were conducted to determine the optimal formulation for the nori-like product (refer to Table 2 for details).

Table 2
Component, target, limit score and dan importance at optimization step

Component	Goal	Lower	Upper	Importance
Ulva lactuca	*Maximum*	23.0	26.0	*****
Gracilaria	*Maximum*	6.0	8.0	*****
Glycerin	*Minimize*	1.5	3.0	****
Unchovy	*Maximum*	2.0	5.0	*****

Nori preparation

The prepared seaweed was boiled for 10 minutes and then drained. Seasoning ingredients, including palm oil, sesame oil, anchovy, oyster sauce, salt, glycerin, and sodium metabisulfite, were added to the formulation as described in Table 1. The mixture was then blended thoroughly to achieve homogeneity.

The pre-prepared seaweed was boiled for 10 minutes and subsequently drained. Following this, the seasoning ingredients including palm oil, sesame oil, anchovy, oyster sauce, salt, glycerin, and sodium metabisulfite were added into the formulation as outlined in Table 1.

The mixture was rigorously blended to ensure a homogeneous consistency. Then, the mixture was poured into a rectangular acrylic tray measuring 24 cm x 22 cm, which had been coated with Teflon sheets to shape it into thin sheet-like products. Following this, the nori was subjected to drying in an oven equipped with a blower at a temperature of 60°C for 6 hours. Once the dried nori was obtained, it underwent a brief frying process in oil at a temperature of 200°C for 30 seconds, resulting in fried nori. Subsequently, the fried nori was allowed to cool to room temperature and was then carefully packaged in plastic before undergoing further analysis (as shown in Fig. 1).

Experiments

The proximate analysis of the raw seaweed materials, Gracilaria and *Ulva lactuca*, was carried out according to the AOAC (2005) procedure. To determine the optimal formula, the nori-like product was formulated using RSM Design Expert 13. Product quality was assessed through sensory analysis, which involved the evaluation of color, texture, appearance, aroma, and taste by a panel of 15 trained individuals. The results of the sensory response test were analyzed using Design Expert 13 software. The optimal formula selected through Design Expert 13 was subsequently verified and underwent a series of quality tests, including evaluations of crispness, color (L*, a, b), proximate analysis, dietary fiber, amino acids, mineral content, and sensory assessment. Additionally, a commercial nori product made from *Porphyra* seaweed was used as a reference for comparison.

Proximate analysis

The proximate analysis of both the seaweed samples and the nori-like product was conducted in accordance with the AOAC's standard methods (2005). Before conducting proximate analyses, specifically for nori sample was ground using a mortar and pestle. To determine the moisture content, the samples were dried for 18 hours at 105°C in a universal oven until a constant weight was achieved (AOAC 925.10). Ash content was determined by incinerating samples in a furnace overnight at 550°C (AOAC 923.03). Protein content was assessed by digesting the samples with concentrated sulfuric acid (H_2SO_4) and a selenium tablet, following the Kjeldahl procedure, and applying a conversion factor of 6.25 (AOAC 981.10). Fat content was determined using the Soxhlet Avanti auto system with petroleum ether as the solvent (AOAC 922.06). Crude fiber and carbohydrate contents were calculated by subtracting the sum of protein, fat, moisture, ash, and crude fiber from 100% (AOAC 962.09). All analyses were conducted in triplicate.

Sensory analysis

The sensory evaluation of the nori samples involved assessments by a panel of 25 trained panelists. They evaluated each sample's attributes, such as color, aroma, taste, texture, and overall acceptability, using a nine-point hedonic scale from 5 to 9 (5 = neither like or dislike; 6 = like slightly; 7 = like moderately; 8 = like very much; 9 = like extremely) (Meilgaard et al. 2016; Lawless and Heymann 2010; Charutigon et al. 2008). Each nori sample was assigned a random three-digit code and then shuffled before being presented on a tray to the panelists. Panelists were instructed to rinse their mouths with water to cleanse their palate before assessing each subsequent sample. A nine-point hedonic scale from 5 to 9 (5 - neither like or dislike, 6 - like slightly, 7 - like moderately, 8 - like very much, 9 - like extremely)

Physical properties of nori formulation

Crispness

The crispness of the nori samples was assessed using a TA.XT. Plus texture analyzer Stable Micro Systems, Surrey, UK). Sheets of nori are cut into small squares approximately 30 mm x 30 mm. Five samples of nori were tested to generate the results below. The spherical probe is connected to the load cell with a probe adaptor (AD/100) on Heavy Duty Platform (HDP/90) with a 5 mm stainless steel spherical probe (P/5S) and using a 5 kg load cell and a 5 mm diameter cylindrical flat-faced probe. The measurements were conducted at a cross-head speed of 1 mm/s, distance of the probe to the nori surface is 20 mm following the procedure outlined by Arimi et al. in 2010.

Colour analysis

The color of the samples was assessed using a HunterLab LabScan XE Spectrophotometer equipped with a D65 light source (Hunter Associates Laboratory, Inc., Reston, VA, USA) to determine the L*, a*, and b* values. Sample preparation and measurement procedures followed the methods outlined by Del Olmo et al. (2018).

Minerals content

The mineral content analysis was performed on the samples. The extraction of minerals from the samples followed the procedure outlined by AOAC (2005) and was conducted using inductively coupled plasma mass spectrometry (ICP-MS). The elements analyzed included calcium (Ca), potassium (K), sodium (Na), magnesium (Mg), manganese (Mn), iron (Fe), copper (Cu), selenium (Se), zinc (Zn), and iodine (I), with specific methods outlined in AOAC standards (AOAC 984.27, 999.11, 986.15). All samples were analyzed in triplicate to ensure accuracy and reliability of the results.

Amino acid analysis

High-Performance Liquid Chromatography (HPLC) was used to determine the amino acid composition in the samples, in accordance with the procedure outlined by Cohen and Michaud (1993). In principle, the proteins present in the samples are subjected to hydrolysis, where they are broken down into their constituent amino acids. Once the hydrolysis process is complete, the resulting amino acids can be accurately quantified and identified using HPLC.

Statistical analysis

The statistical analysis was carried out using SPSS version 25, using a one-way analysis of variance (one-way ANOVA). Subsequently, a post hoc Tukey's Honestly Significant Difference (HSD) test was applied with a significance threshold of $p < 0.05$. All experimental data were presented as the mean values from three repetitions along with their respective standard deviations.

Results

Proximate composition of seaweeds

The results of the proximate composition analysis for *Ulva lactuca* and *Gracilaria* are summarized in Table 2. *Gracilaria* exhibited higher fat and ash content in comparison to *Ulva lactuca*, while its protein and carbohydrate content were found to be lower than those in *Ulva lactuca*. Specifically, the fat content of *Gracilaria* in this study was measured at 2.39% ± 0.46%. It's noteworthy that other studies conducted by Rasyid et al. (2019), Purwaningsih and Deskawati (2020), and Radha (2018) reported varying fat content values for *Gracilara*, specifically 0.19%, 0.6%, and 0.86%, respectively.

The ash content of *Gracilaria* in this study was measured at 37.41% ± 3.58%. This result notably exceeded values reported by other studies, such as Rasyid et al. (2019) with 6.78%, Purwaningsih and Deskawati (2020) with 24.83% ± 0.83%, and Radha (2018) with 7.83%. In terms of protein content, *Gracilaria* in this study contained 7.8%, which was comparatively lower than values reported by Rasyid et al. (2019) at 10.86%, Purwaningsih and Deskawati (2020) at 9.36%, and Yudiati et al. (2020) at 15.38%. Regarding carbohydrate content, *Gracilaria* in this study contained 40.86%. While this value was lower than what was reported by Rasyid et al. (2019) at 63.13%, Radha (2018) at 86.58%, and Yudiati et al. (2020) at 61.38%, it notably exceeded the value reported by Purwaningsih and Deskawati (2020) at 11.05%.

In this study, the fat content of *Ulva lactuca* was found to be 0.45%, which is notably lower compared to the values reported in other studies. For instance, Costa et al. (2018) reported a much higher fat content of 5.7%, while Morales et al. (2018) found it to be 1.7%, and Nufus et al. (2017) recorded a value of 1.43%. In terms of ash content, *Ulva lactuca* in this study contained 28.91%. This value falls below that reported by Elena et al. (2018), which was 33.07%, but it is higher than the values reported by Nufus et al. (2017) at 24.97% and Rasyid (2017) at 11.2%. The protein content of *Ulva lactuca* in this study was measured at 14.36%. This value is lower than what was found in studies by Costa et al. (2018) at 17.43% and Elena et al. (2018) at 17.2%. However, it surpasses the protein content reported by Nufus et al. (2017) at 5.14% and Rasyid (2017) at 13.6%. Regarding carbohydrate content, *Ulva lactuca* in this study contained 49.96%, which is lower than the values reported by Costa et al. (2018) at 62.93% and Rasyid (2017) at 58.1%. Nevertheless, it exceeds the carbohydrate content reported by Nufus et al. (2017) at 36.49%.

Table 3
Proximate composition of *Ulva lactuca* and *Gracilaria*

Component	**Unit**	**Sample**	
		Ulva lactuca	***Gracilaria***
Crude Fat	%	0.45 ± 0.01	2.39 ± 0.46
Moisture content	%	6.32 ± 0.25	11.54 ± 0.11
Ash	%	28.91 ± 1.21	37.41 ± 3.58
Protein	%	14.36 ± 0.23	7.8 ± 0.28
Carbohydrate	%	62.06 ± 0.60	62.06 ± 0.60

Values are mean ± standard deviations, n = 3, the same superscripts have no significant difference ($p > 0.01$).

Nori produced using formulas 1–6 exhibits a neat appearance with a bright green color. In contrast, nori from formulas 7–10 maintains its neatness but exhibits a slightly duller appearance with a brownish color. Nori produced with formulas 11, 12, 14, and 15 appears less tidy, featuring cracks and displaying a greenish-yellow color. Conversely, nori formulas 13 and 16 appear neater with a slightly yellowish-green coloration.

Sensory evaluation

Table 4
The sensory evaluation of nori-like product.

Runs	Colour	Texture	Appearance	Aroma	Taste
F1	8.0 ± 1.10^{a}	7.6 ± 1.26^{b}	8.0 ± 1.10^{b}	7.3 ± 0.82^{a}	7.0 ± 1.26^{b}
F2	9.0 ± 0.00^{b}	9.0 ± 0.00^{e}	7.3 ± 1.51^{a}	7.7 ± 1.03^{b}	8.7 ± 1.63^{d}
F3	8.7 ± 0.82^{a}	7.7 ± 1.63^{b}	7.7 ± 1.63^{a}	7.7 ± 1.03^{b}	8.0 ± 1.03^{c}
F4	8.7 ± 0.82^{a}	$5.7. \pm 1.03^{a}$	8.3 ± 1.03^{b}	7.7 ± 1.03^{b}	6.0 ± 1.51^{a}
F5	8.0 ± 1.10^{a}	7.0 ± 1.79^{b}	7.7 ± 1.63^{a}	7.3 ± 1.53^{a}	7.2 ± 1.03^{b}
F6	9.0 ± 0.00^{b}	8.0 ± 1.0^{c}	9.0 ± 0.00^{c}	7.3 ± 0.82^{a}	8.0 ± 0.82^{c}
F7	8.7 ± 0.82^{a}	7.0 ± 1.79^{b}	7.7 ± 1.97^{a}	7.3 ± 0.82^{a}	7.2 ± 1.10^{b}
F8	8.3 ± 1.03^{a}	7.0 ± 1.26^{b}	8.7 ± 0.82^{b}	7.0 ± 1.26^{a}	7.2 ± 1.26^{b}
F9	7.7 ± 1.03^{a}	5.7 ± 1.03^{a}	8.0 ± 1.10^{b}	7.7 ± 1.03^{b}	8.5 ± 1.51^{d}
F10	8.3 ± 1.03^{a}	9.0 ± 0.00^{e}	8.3 ± 1.03^{b}	7.8 ± 0.98^{b}	8.6 ± 0.82^{d}
F11	9.0 ± 0.00^{b}	8.0 ± 1.1^{c}	8.3 ± 1.03^{b}	7.8 ± 0.98^{b}	8.0 ± 1.26^{c}
F12	9.0 ± 0.00^{b}	7.3 ± 0.82^{b}	8.7 ± 0.82^{b}	7.7 ± 1.03^{b}	7.3 ± 1.79^{b}
F13	9.0 ± 0.00^{b}	8.3 ± 1.03	9.0 ± 0.00^{c}	7.8 ± 0.98^{b}	8.3 ± 0.82^{c}
F14	8.3 ± 1.03^{a}	7.7 ± 1.63^{b}	8.0 ± 1.03^{b}	7.7 ± 1.03^{b}	7.5 ± 1.51^{b}
F15	8.0 ± 1.10^{a}	8.0 ± 1.67^{c}	7.7 ± 1.63^{a}	7.7 ± 1.03^{b}	7.8 ± 1.26^{b}
F16	9.0 ± 0.00^{b}	6.3 ± 1.03^{a}	8.3 ± 1.63^{b}	7.7 ± 1.03^{b}	6.3 ± 1.26^{a}
Note: Values with the same letters have no significant difference ($p > 0.01$)					

Sensory attributes were evaluated using a nine-point hedonic scale from 5 to 9 (5 - neither like or dislike, 6 - like slightly, 7 - like moderately, 8 - like very much, 9 - like extremely)

noted: nori's score of 5–6 is rejected and > 7 is accepted.

Table 5
Results of response analysis of ANOVA on *Design Expert* 13

Response				
Parameters	P-Value	Lack of Fit	Adeq precision	R^2
Colour	0.0119	0.1590	7.8489	0.9179
Texture	0.0004	0.1026	9.6506	0.7719
Appearance	0.0114	0.1703	7.9094	0.9191
Aroma	0.0268	0.3591	8.0803	0.8896
Taste	0.0013	0.1301	13.8904	0.9625

The ANOVA analyses for the overall sensory attributes, with the exception of texture, have successfully met the desirability criteria, yielding R2 values approaching (Aini et al. 2019). Additionally, the classification categories for desirability, as reported by Masoumi et al. 2015, indicate that desirability scores fall within the range of 0.8-1.0 considered indicative of accepted or good quality. If the score is less than 0.63, it is indicative of low quality, and if it falls below 0.37, the prediction parameter is deemed unacceptable. All sensory attributes also exhibit a lack-of-fit score greater than 0.05, signifying that they have met the criteria for a satisfactory response. Additionally, the Adequate Precision scores for color, texture, appearance, aroma, and taste attributes were all above 4.0, categorizing them as 'good'. So the response used to determine optimization criteria was all parameter with desirability score > 0.91 showing that the optimum prediction formula was accepted with good quality.

Table 6
Response, target, limit score, and dan importance at optimization step

Component	**Goal**	**Lower**	**Upper**	**Importance**
Colour	*Maximum*	6.0	9.0	*****
Texture	*Maximum*	7.3	9.0	*****
Appearance	*in range*	6.0	9.0	***
Aroma	*Maximum*	7.0	8.8	*****
Taste	*Maximum*	6.3	9.0	*****

Correlations among parameters for each response can be expressed using a mathematical model, where A represents anchovy concentration (%), B represents glycerol concentration (%), C represents *Ulva lactuca* concentration (%), and D represents *Gracilaria* concentration (%). The response model is defined by Equation, and the sensory response model is defined by Equations 1–5 as follows:

$$Colour = 20.8A + 4.02B + 0.883C + 30.75D - 1.16AB - 0.58AC - 1.51AD + 0.28BC - 2.202BD - 1.08CD \ldots\ldots (1)$$

$$Texture = 0.24A - 1.18B + 0.32C + 0.19D \ldots\ldots (2)$$

$$Appearance = 20.93A + 2.47B + 0.86C + 30.75D - 1.08AB - 0.59AC - 1.53AD + 0.31BC - 1.98BD - 1.08CD \ldots\ldots (3)$$

$$Aroma = 9.35A - 1622B + 0.39C + 8.58D - 0.66AB - 0.3AC - 0.18AD + 0.73BC - 0.24BD - 0.33CD \ldots\ldots (4)$$

$$Taste = -14.11A - 0.34B - 0.98C - 7.14D + 0.001AB + 0.54AC + 0.60AD \ldots\ldots (5)$$

According to the equations above, maximizing the criteria for color and appearance scores can be done by increasing the concentration of all variables. Conversely, the addition of glycerol led to a reduction in texture and aroma attributes, while the inclusion of anchovy resulted in a decrease in the product's taste. The sensory analysis, performed using Mixture Design Type I-Optimal with a 3D chord model, is visually depicted in Fig. 2.

Based on sensory analysis, the optimal formula for the nori-like product sheet was predicted to consist of the following ingredients: *Ulva lactuca* (25.1%), *Gracilaria* 7.4%), glycerol (2.5%), and anchovy (4.1%). This formulation resulted in an average sensory score of 6.9 for color, 7.4 for texture, 6.9 for appearance, 7.4 for aroma, and 8.0 for taste. A comparison between the optimized nori-like product and commercially available nori is detailed in Table 7.

Table 7
Comparison of Predicted and Experimental Values for the response Variable

Parameters	**Predicted Nori-like product sheet**		**Nori-like product sheet observation**	**Commercial nori**
	95% PI low	**95% PI High**		
Colour	5.7	8.1	8.1	8.4
Texture	6.3	8.5	8.1	8.8
Appearance	5.7	8.1	8.0	7.4
Aroma	6.4	8.4	8.2	8.4
Taste	7.3	8.6	7.8	8.4

The results of the sensory hedonic response verification tests, including evaluations of color, texture, appearance, aroma, and taste, fall within the selected range obtained from the optimization of the mixture design. The sensory quality of the nori-like product closely resembles that of commercial nori. Notably, the appearance attribute of the nori-like product even surpasses that of commercial nori.

Physical properties

The analysis of crispness and color is presented in Table 8. According to Evawati (1997), the crispness of a product is influenced by its water content. Having a certain level of water in the porous between cells can reduce the product's crispness. From the table, it is clear that the selected nori-like product showed a higher crispness rating (70 g) compared to the commercial nori (55 g).

In terms of the color analysis, both the nori-like product and commercial nori exhibited brightness values (L*) below 50, indicating the nori-like product as having a dark color. Moreover, the brightness surface color for the nori-like product was found lower than that of the commercial nori. This increased darkness might be attributed not only to the chlorophyll content in *Ulva lactuca* but also to the use of some seasonings such as sesame oil and oyster sauce.

Table 8
Crispness and colour of the nori like-product from the selected formula

Products	**Crispness (g)**	**Colour parameters**		
		L*	***-a****	***-b****
Nori-like product	70.318 ± 15.1	29.50	-2.13	7.23
Commercial Nori	54.865 ± 12.0	32.13	-3.41	9.79

The dark surface color of the nori was further supported by the redness (a*) values, which were − 2.13 for the nori-like product and − 3.41 for commercial nori, indicating that the nori-like product exhibited a greenish tint. Abirami and Kowsalya (2011) reported that *Ulva lactuca*, which is a green alga with a high chlorophyll content (including both chlorophyll a and b), contributes to this coloration. Chen and Roca (2018) also noted that the chlorophyll content in *Ulva lactuca* is approximately 9.216 mg/g.

Furthermore, the b* value for both the nori-like product (7.23) and commercial nori (9.79) suggests that both samples had a yellowish tint. The color of the nori-like product aligns with findings by Sinurat et al. (2022), who investigated a nori-like product made from a combination of seaweeds, including *Gracilaria*, *Ulva lactuca*, and *Caulerpa*, resulting in a color range of 3.31 to 22.25, while commercial nori had a color value of 5.37. Overall, these results indicate that the color of nori is influenced not only by the types of seaweed and seasonings used in its formulation but also by the drying and frying processes involved.

Table 9
Chemical compositions of the selected optimum nori-like product compared to commercial nori.

Parameters	Nori-like product	Commercial nori
Dietary Fibre (g.100 g^{-1})	65.22	62.75
Moisture content (g.100 g^{-1})	4.5	3.30
Ash (g.100 g^{-1})	14.41	3.41
Carbohydrate (g.100 g^{-1})	27.05	11.46
Protein (g.100 g^{-1})	12.08	14.54
Fat (g.100 g^{-1})	43.94	70.94
Sodium (mg kg^{-1})	2188	48547
Iron (mg kg^{-1})	42	41
Potassium (mg kg^{-1})	4019	295
Calcium (mg kg^{-1})	596	2310
Copper(µg/kg)	2.7	0.9
Phosphor (mg kg^{-1})	3055	1012
Magnesium (mg kg^{-1})	1126	3158
Selenium (µg kg^{-1})	0.06	0.13
Zinc (mg kg^{-1})	18	82
- : not available		

Amino acid

The quality of nori nutrition can be evaluated by examining its protein's amino acid composition, which can also influence the taste characteristics of the product (Pratama et al. 2017). According to Deng et al. (2014), amino acids and peptides play a significant role in determining the flavor of aquatic products. The amino acid profile of the nori-like product is provided in Table 10.

Table 10
The amino acids profile of the nori-like product compared to commercial nori.

No	Types Amino Acid	Nori-like product sheet	Commercial Nori
	Essensial Amino Acid	(mg g^{-1})	(mg g^{-1})
1	Lysine	6.49	6.52
2	Leucine	3.36	3.75
3	Valine	5.51	5.11
4	Threonine	3.29	3.84
5	Hystidine	1.24	1.74
6	Methionine	1.31	1.52
7	Phenylalanine	0.06	0.07
8	Tryptophan	0.31	0.34
9	Arginine	6.13	4.36
	Total	27.7	27.25
	Percentage (%)	57.07	59.04
	Non Essensial Amino Acid		
1	Alanine	2.85	2.01
2	Glutamine	6.68	6.59
3	Hydroxy-L-Proline	1.7	2.31
4	Proline	4.1	3.52
5	Serine	1.16	0.99
6	Taurine	1.4	0.8
7	Tyrosine	2.94	2.68
	Total	20.83	18.9
	Percentage (%)	42.29	40.95

Based on the amino acid profile, the nori-like product was found to contain 8 essential amino acids: lysine, leucine, valine, threonine, phenylalanine, histidine, methionine, and tryptophan, along with 1 semi-essential amino acid, arginine. Notably, isoleucine, an essential amino acid, was not detected. Additionally, 7 non-essential amino acids were identified, including alanine, glutamate, hydroxy L-proline, proline, serine, and tyrosine. When comparing the quantities of each amino acid in both the nori-like products and commercial nori, it was evident that the essential amino acids were present in higher concentrations than the non-essential ones (refer to Table 11).

From the results above, it's worth noting that the amino acid content in the nori-like product surpasses that found in fresh gourami fish, as reported in the study by Pratama et al. (2017), where it was only 17.8 mg g-1. The notable concentration of amino acids in the nori-like product can be attributed to the inclusion of anchovy flour. Specifically, the nori-like product exhibits higher levels of the amino acids valine and arginine in comparison to commercial nori. Nevertheless, both nori varieties contain higher concentrations of the non-essential amino acid glutamine when compared to other amino acids.

Discussion

Proximate composition

The fat content of *Ulva lactuca* and *Gracilaria* seaweed in this study was found to be relatively low, specifically, 0.45% and 2.39%, respectively. These results align with the findings of Rasyid (2017) who reported a fat content of 0.19% for the *Ulva lactuca* harvested from Pameungpeuk, West Java. However, the fat content of *Gracilaria* was higher than previously reported values by Rasyid et al. (2019), Purwaningsih and Deskawati (2020), and Radha (2018), which were 0.19%, 0.6%, and 0.86%, respectively.

In comparison to terrestrial plants, seaweed generally contains lower fat levels, typically less than 4% (Kumar et al. 2021). It's worth noting that the fat content of seaweed can vary depending on factors such as location and seasonal variations (Schmid et al. 2018).

The moisture content in food products is of utmost importance as it significantly affects the product's quality and shelf life. Seaweeds are known for their typically high moisture content. For instance, fresh Ulva was reported to have a moisture content of approximately 80% (Uribe et al. 2018), while *Gracilaria* ranged from 75–85% (Jasmadi et al. 2023). However, during the drying process, seaweed's moisture content undergoes a substantial reduction. In this study, the moisture content of dried Ulva was found to be lower than that reported by Rasyid (2017), who recorded it at 16.9%. Conversely, the moisture content of dried *Gracilaria* was approximately 11.54%, which closely aligns with the findings of Rosemary et al. (2019), who reported a moisture content of around 10.40%.

Ash content serves as an indicator of the mineral content in a material and is influenced by various factors, including the seaweed's environment and drying method (Kumar et al. 2021). In this study, notably high ash content was observed, measuring at 28.9% for *Ulva lactuca* and 37.4% for *Gracilaria*. It's important to note that ash content can vary significantly among different seaweed species, depending on factors such as oceanic residency periods, geographical harvesting locations, exposure to waves, seasonal fluctuations, environmental conditions, physiological characteristics, processing methods, and mineralization techniques (Yoshie et al. 1994).

Protein content plays a crucial role in determining the nutritional value of food, mainly due to its amino acid profile. In this study, Ulva's protein content was found to be 14.36%. This value, while slightly lower than the values reported by Costa et al. (2018) at 17.43% and Morales et al. (2018) at 17.20%, was notably higher than the protein content found in *Gracilaria*, which found at 7.8%. This observation aligns with Fleurence (1999), who reported that factors such as species, seasons, and the marine environment have a notable impact on protein content.

In this study, we determined the carbohydrate content using a by-differences method. Interestingly, both *Ulva lactuca* and *Gracilaria* showed a similar carbohydrate content of approximately 62%, which closely aligns with the findings reported by Rasyid (2017) for *Ulva lactuca* (58.1%) and Rasyid (2019) for *Gracilaria* (63.13%).

Carbohydrates play a crucial role as a primary source of energy for metabolism, making them a fundamental component of the diet. Seaweed carbohydrates, in particular, are rich in dietary fibers that have been shown to have a positive impact on mitigating metabolic syndromes associated with obesity, including conditions like type 2 diabetes and cardiovascular disease. These dietary fibers, especially the soluble and viscous types found in seaweed, are known to lower blood sugar levels, address dyslipidemia, and help regulate hunger and energy intake (Jakobsdottir et al., 2014). It's worth noting that various factors, including temperature, season, and species, can influence the carbohydrate content in seaweed (Enquist-newman et al., 2014).

Sensory acceptance

The R^2 value for the texture response is 7.7, which falls within the ideal R^2 range recommended by Aini et al. (2019). This alignment is likely due to the presence of glycerol in the formula for the nori-like product, as glycerol is known for its hydrophilic properties. As reported by Sinurat et al. (2021), glycerol's hygroscopic nature can impact the product's texture when it is unpackaged.

It's worth noting that the texture of the nori-like product can be influenced by various factors, including the chosen techniques and packaging materials. In this study, aluminum foil in combination with silica gel for packaging the nori-like product have been used. However, this packaging approach proved inadequate in maintaining the product's initial texture. An alternative approach suggested to prevent texture changes involves the use of nitrogen flushing technology, as suggested by Singh et al. (2022).

In addition, the overall acceptance of the product by the panelists, including aspects like color, appearance, aroma, and taste, is significantly affected by the vibrant green color of *Ulva lactuca*. This green color is attributed to the high chlorophyll content in *Ulva lactuca*, resulting in a nori-like product that the panelists favor (Litter et al. 1989; Martin et al. 2021). Furthermore, the product's appearance and aroma are also influenced by the distinct characteristics of *Ulva lactuca* and the seasonings incorporated into the nori-like product formula. The distinctive aroma of *Ulva lactuca* is influenced by certain amino acids that contribute to the formation of volatile compounds. These amino acids include branched-chain amino acids (L-leucine, L-isoleucine, and L-valine), as well as L-methionine and aromatic amino acids (Maoz et al. 2022).

The panelists' preference for the nori's flavor appears to be influenced by more than just the utilization of *Ulva lactuca* seaweed as the main ingredient. The addition of anchovy seems also to play a significant role in enhancing the panelists' liking for the taste. Anchovy contains L-glutamic acid and 5' nucleotides in a 1:1 ratio, resulting in an umami taste that is seven times stronger compared to the umami taste of glutamate alone. Furthermore, the presence of Na^+ and Cl^- ions substantially amplifies the overall umami intensity in ingredients like mushrooms and dried bonito (Hakimi et al. 2022).

The sensory response verification results indicate that the predicted response quality interval (PI) aligns with the observed results of the optimum formula suggested by the Design Expert software. This alignment demonstrates the appropriateness of the mixture design model chosen for the analysis.

Physical properties

Crispness

The crispness in food is often associated with the firmness and freshness of food (Tunick et al. 2013). In this study, the nori-like product had a higher crispness value (70.31 g) compared to commercial nori (54.86 g). This means the nori-like product was crunchier, indicating a lower level of hardness (Andarwulan et al. 2011). During heating, moisture released from food ingredients forms air bubbles that burst, creating pores on the product's surface (Kawas and Moreira 2001). Based on the texture observations, it was evident that the nori-like product exhibited significantly higher crispness compared to the commercial nori ($p < 0.05$). While moisture content is the primary factor contributing to this difference, the crispness values are also influenced by the composition of components within the product. However, in this case, the difference in crispness between the two nori products was not primarily due to their moisture content, as both samples had similar moisture levels. Instead, the main factor responsible for the increased crispness of the nori-like product, in contrast to the commercial one, was its higher carbohydrate and mineral content and lower fat content. Elevated carbohydrate levels might lead to a crisper texture as the carbohydrates dehydrate during processing, forming a crispy crust. Moreover, the presence of additional ingredients like fats and proteins from added seasonings such as oyster oil and anchovy powder may also interact with carbohydrates, affecting crispness (Fransiska et al. 2022). Additionally, the higher mineral content may lead to a rougher surface and increased porosity in food products processed through heating methods such as baking and frying. Consequently, the complex interplay of these components contributes to the notably crispy texture of the nori-like product.

It's important to note that the fiber content in food products can increase their hardness. In the case of nori, Zakaria et al. (2017) found that nori made from *Ulva lactuca* contains more total dietary fiber compared to commercial nori made from *Phorphyra*, which likely contributes to its firmer texture.

Colour

The lightness values (L*) for both the nori-like product and commercial nori were measured at 29.50 and 32.13, respectively, indicating a dark color (L* < 50). The dark surface color of the resulting nori is influenced by various factors, including the choice of raw materials, seasonings, and the drying process. In the case of nori-like product, the raw materials include *Ulva lactuca* seaweed, which has a naturally dark green color, and *Gracilaria*, which also contributes to the overall dark coloration on the product surface. Furthermore, the inclusion of seasonings in the formulation, such as oyster sauce and sesame oil, also plays a role in imparting a dark color to the nori. Additionally, the drying process, carried out using a food dehydrator at a temperature of 60°C for 6 hours, contributes to browning and results in a darker color for the nori-like product. It's worth noting that the negative a* values for both the nori-like product and commercial nori indicate a greenish color of the product. The green color observed is primarily due to the use of *Ulva lactuca*, which naturally has a dark green color because of its high chlorophyll content. The chlorophyll content in Ulva has been reported as 6.79 mg L-1 (Samad et al. 2021) and 4.652 mg.g-1 (Kurniasih et al. 2014). Chlorophyll and its derivatives have various biological effects, including cancer prevention, antioxidant and antimutagenic properties, mutagen trapping, regulation of xenobiotic metabolism, induction of apoptosis, antibacterial properties, and anti-inflammatory activity (Zepka et al. 2019). The + b* values represent the degree of yellowness in the sample's surface color. The b* value for the nori-like product was measured at 7.23, while for commercial nori, it was 9.79. The yellowish color in the nori-like product is due to specific pigments present in the *Ulva* and *Gracilaria* seaweeds, which are the primary raw materials used. These seaweeds contain yellow pigments like carotenoids and xanthophylls, as reported by Pesang et al. (2020) for *Ulva lactuca*. *Gracilaria* is also known to contain carotenoids at levels ranging from 31.6 to 35.5 μmol.g-1, as noted by Febrianto et al. (2019). Additionally, the inclusion of vegetable oil, rich in carotenoids, in the formula may have contributed to the yellowish appearance of the final product.

Proximate, dietary fibre, and mineral content of the nori-like product

Differences in the proximate compositions between the nori-like product and commercial nori can be attributed to various factors, including variations in raw materials, processing methods, and the specific environmental conditions where the seaweed was farmed and harvested (Erniati et al. 2018; Sinurat et al. 2022).

The relatively high moisture content in the nori-like product raises concerns about its shelf life and preservation. Products with elevated moisture levels are generally more susceptible to microbial growth, which could affect their shelf life (Ayub et al. 2003). However, it's essential to note that the moisture content of the nori-like product meets both national and international standards for nori. This compliance confirms the product's safety and suitability for consumption.

The protein content of the nori-like product was lower than that of commercial nori and significantly lower than that of nori made from *Porphyra* raw materials. This difference could be attributed to various factors, such as the species of seaweed used, processing methods, or inherent variations in the nutritional composition of the seaweed itself (Erniati et al. 2018). The lower protein content has implications for the product's nutritional value, given that protein is a vital nutrient for human health.

On the other hand, the fat content of the nori-like product is much lower than that of commercial nori but still higher than reported in other studies on nori. This lower fat content can be viewed as a positive aspect, potentially making the product more appealing to consumers seeking low-fat food options.

Furthermore, the carbohydrate content of the nori-like product is higher than that of commercial nori but falls below the levels found in other studies. Since carbohydrates are a primary source of energy, this difference could affect the overall energy value of the product.

Importantly, the dietary fiber content of the nori-like product does not significantly differ from that of commercial nori. Dietary fiber plays a crucial role in promoting a healthy diet, as it can help prevent conditions like heart disease, diabetes, weight gain, certain types of cancer, and improve digestive health (McKeown et al. 2022).

The mineral composition of the nori-like product significantly differs from that of the commercial nori, with potassium, phosphorus, and sodium being the most abundant minerals in the former. In contrast, sodium is the predominant mineral in commercial nori. Notably, the nori-like product contains higher levels of certain minerals, such as iron, potassium, copper, and phosphorus, which could potentially enhance its nutritional value.

However, it's important to highlight that commercial nori contains higher levels of other minerals like sodium, calcium, magnesium, selenium, and zinc. These variations in mineral content may stem from a range of factors, including the species of seaweed used, the seaweed's growth conditions, and the processing methods employed (Sinurat et al. 2022). For instance, seaweeds cultivated in different locations or under distinct environmental conditions may exhibit varying mineral compositions.

Amino acids profile

In principle, the quality of a protein is considered high if it can provide essential amino acids in accordance with the human body's nutritional requirements (Brestensky et al. 2019). Based on these findings, we can evaluate how well nori meets the body's amino acid needs by following the standard pattern of essential amino acids established by the FAO (Egiyanti et al. 2019). This evaluation is calculated by dividing the amino acid content in the nori product by the FAO's established standard amino acid values and then multiplying the result by 100. Amino acids with values below 80 are considered limiting factors, indicating that they are insufficient to meet essential amino acid requirements.

The results of the adequacy value calculations for amino acids in both the nori-like product and commercial nori are presented in Table 12. According to these calculations, it is evident that amino acids such as leucine, methionine, phenylalanine, and tyrosine in both the nori-like product and commercial nori fall short of meeting the FAO's standard amino acid requirements, as their values are below 80. This inadequacy is attributed to the absence of amino acids isoleucine and cysteine in both the nori-like product and commercial nori.

Tabel 12 Amino Acid Adequacy Values for Nori-Like Products and Commercial Nori

Essensial Amino Acid	FAO Standard	Nori-like product	Commercial Nori
Isoleusin	4	0	0
Leusine	7	48	53.57
Lysine	5.5	118	118
Metheonine + Sistein	3.5	37.42	43.83
Fenilalanie + Tirosine	6	50	45.83
Threonine	4	82.25	96
Valine	5	119	102

According to Zhao et al. (2016), glutamic acid is responsible for enhancing the umami taste, which impacts the savory flavor of the resulting nori. Furthermore, Sun et al. (2017) have reported that glycine, alanine, serine, and threonine contribute to sweetness, whereas arginine, leucine, valine, methionine, phenylalanine, histidine, and isoleucine contribute to bitterness in the taste profile of nori.

Conclusion

The optimal formulation for processing the nori-like product, as determined through RSM Design Expert 13, resulted in a final product characteristic comparable to commercial nori based on sensory evaluation and amino acid analysis. However, the overall protein of the nori-like product was found slightly lower compared to commercial nori. On the positive side, the nori-like product had higher levels of dietary fiber and fat content. In terms of mineral content, the nori-like product showed elevated levels of potassium and phosphorus, while other minerals remained largely consistent.

Declarations

Author contributions Ellya Sinurat, Sihono, Fateha - study conception and experimental design, material preparation, sample collection and analysis, data analysis, original draft preparation, manuscript review and editing. Th. Dwi Suryaningrum, Dina Fransiska, Agus - Study conception and experimental design, funding acquisition, manuscript review and editing, data elaboration, supervision of laboratory work and study. Nurhayati, Bakti Berlyanto Sedayu, Bagus SBU, Waryanto - Manuscript review and editing and study.

Funding

This research was supported by the National Research and Innovation Agency, Indonesia

The authors are grateful for the research grant from the Lembaga Pengelola Dana Pendidikan–Ministry of Finance Republic of Indonesia through an awarded Riset dan Inovasi untuk Indonesia Maju scheme with grant number 82/II.7/HK/2022.

Competing interest The authors declare no conflict of interest regarding the publication of this paper.

Informed Consent Statement Informed consent was obtained from all panelists involved in the sensory evaluation study.

Availability of data Not Applicable

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Figures

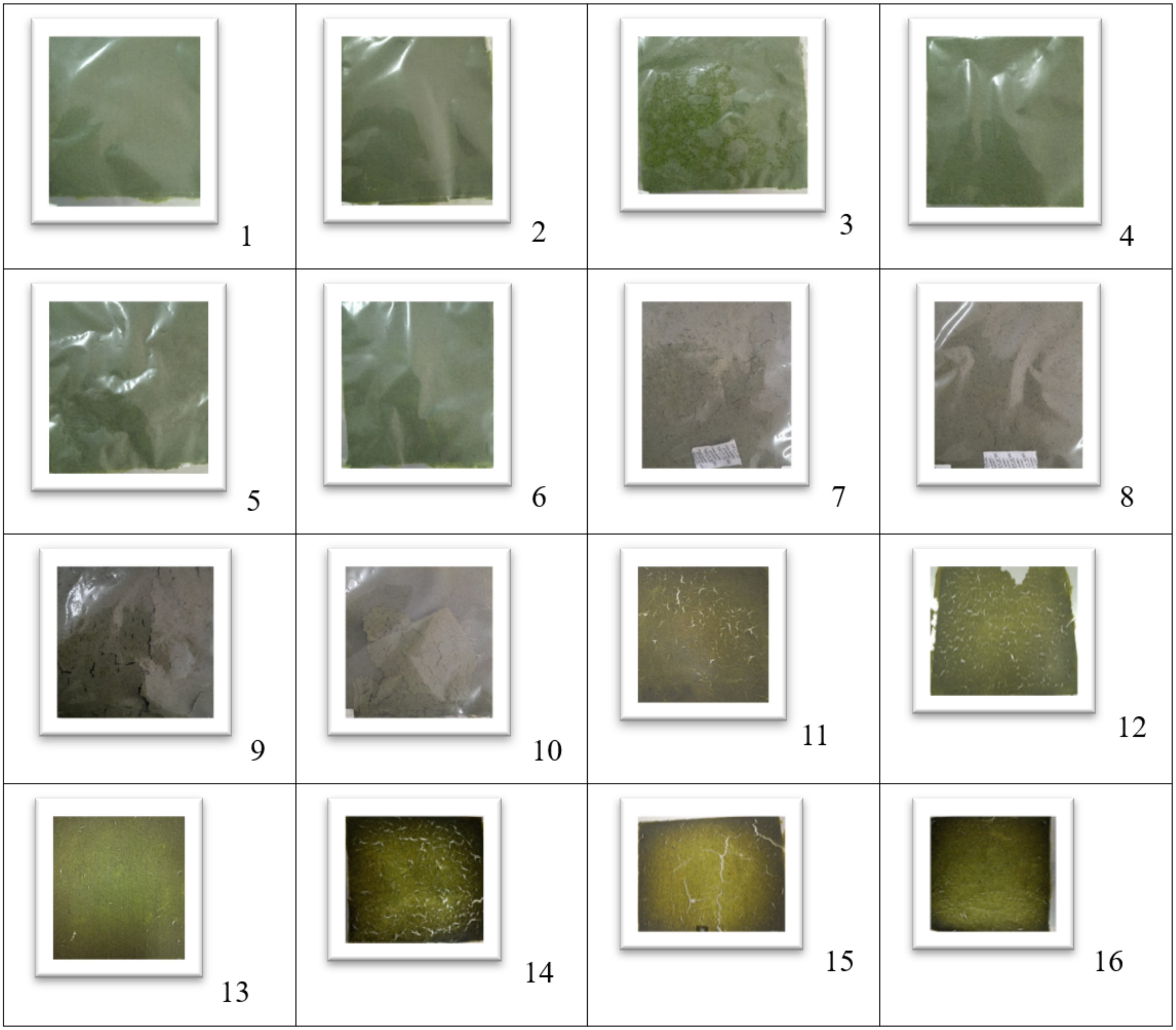

Figure 1

Nori-like product sheet runs 1-16

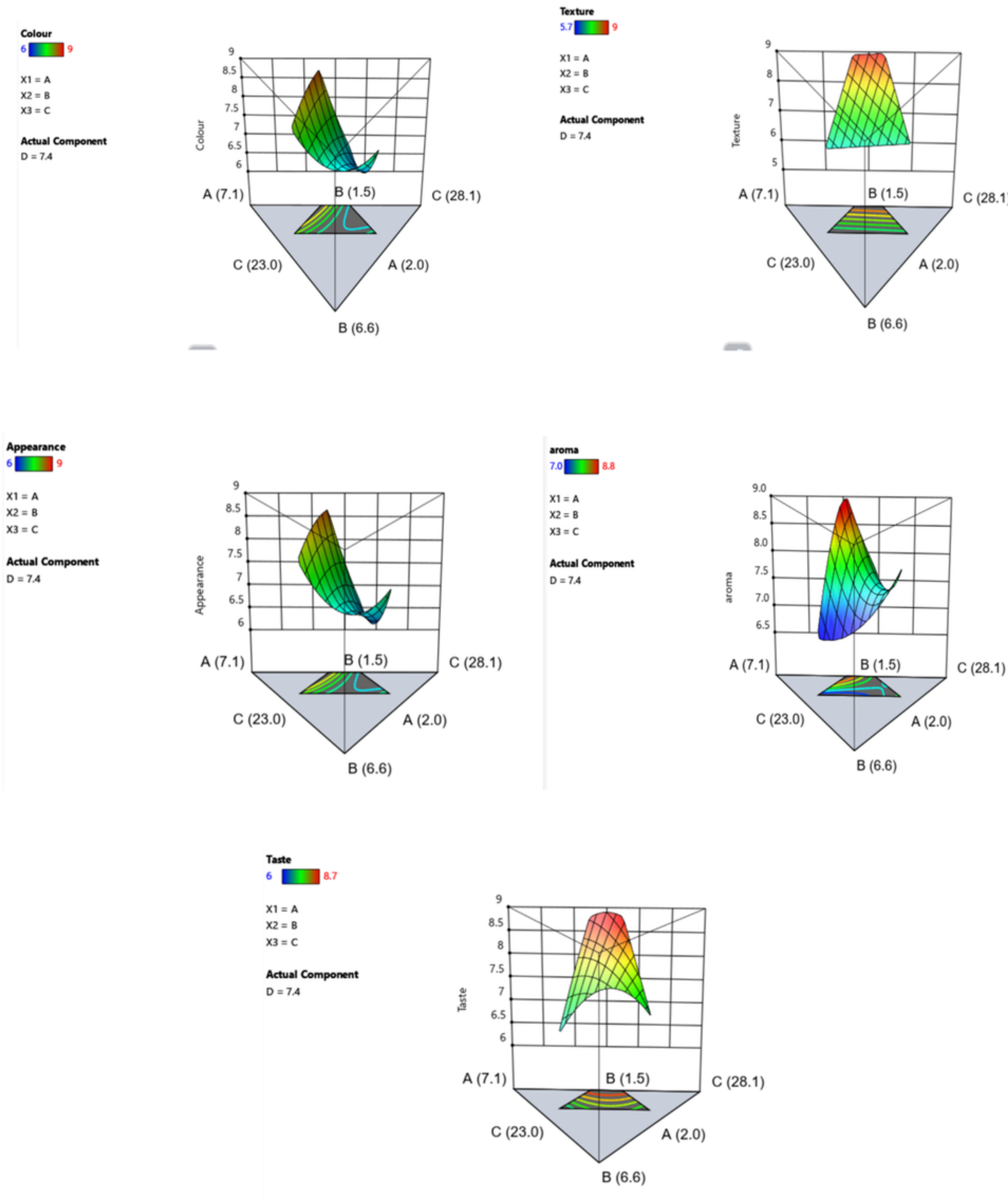

Figure 2

Mixture design I-Optimal sensory parameter of nori-like product