

Flavor Enrichment of Nori-like *Ulva lactuca* with *Terasi* and *Rusip*: Sensory, Physical and Chemical Characteristics

Joko Santoso^{1*}, M. Haekal Tiftazani¹, Wahyu Ramadhan^{1,2}, Simson Masengi³, I Ketut Sumandiarsa⁴



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¹Department of Aquatic Product Technology, Faculty of Fisheries and Marine Sciences, IPB University (Bogor Agricultural University), Bogor, Indonesia, 16680

²Center for Coastal and Marine Resources Studies (PKSPL), International Research Institute (LRI) Maritime, Ocean, and Fisheries (i-MAR), IPB University Baranangsiang Campus, Bogor, Indonesia 16127

³Fish Processing Study Program, the Jakarta Technical University of Fisheries, Jl. AUP Pasar Minggu, Jakarta, Indonesia, 12520

⁴ Marine and Fisheries Polytechnic of Jembrana, Pengambangan, Negara, Jembrana Regency, Bali, Indonesia, 82218

*Corresponding author: jsantoso@apps.ipb.ac.id

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Abstract

In 2020, the demand for nori in Indonesia was valued at USD 4.65 million; however, domestic production remains unfeasible. This study investigates the development of nori-like products using locally available seaweed, *Ulva lactuca*, and introduces novel flavors through the incorporation of traditional Indonesian fermentation products, namely *terasi* and *rusip*. Nori-like products were formulated by adding 2% *terasi* and 3% *rusip*, respectively. These products were then evaluated against commercial nori based on their chemical, physical, and sensory characteristics, employing Quantitative Descriptive Analysis (QDA) and volatile compound analysis using Headspace Gas Chromatography-Mass Spectrometry (HS-GC-MS). The QDA results indicated that the 2% *terasi* nori-like product exhibited a moderately salty, umami flavor with a roasted aroma, while the 3% *rusip* variant demonstrated a more pronounced umami taste and roasted scent. Proximate analysis revealed lower protein content in the nori-like samples (18.25% for *terasi* and 15.38% for *rusip*) compared to the commercial nori (38.03%). The amino acid profiles of the nori-like products were found to predominantly contain glutamic acid, aspartic acid, alanine, and leucine, similar to commercial nori. Texture analysis revealed that the compressive strength of the nori-like products was lower than that of the commercial nori. However, the color of the Nori-like product enriched with *Terasi* closely resembled that of the commercial product. Volatile compound screening confirmed that both *terasi* and *rusip* significantly enhanced the flavor profiles of the nori-like products. This study suggests that local fermentation products can be utilized to develop sustainable and innovative alternatives to traditional nori.

Keywords: nori-like, *rusip*, *terasi*, volatile compound

Introduction

Nori is a traditional Japanese food product made from red seaweed, primarily *Porphyra* spp., is processed into thin, roasted sheets and valued for its umami-rich flavor (Kawashima et al., 2018). Indonesia imported nori valued at USD 4.65 million in 2020, underscoring rising domestic demand amid expanding sushi and seaweed-based food consumption (ITC, 2025). The increasing demand has prompted the government to prioritize domestic nori production, positioning it as a local flagship product. In Japan, nori primarily derives from *Porphyra* species, which inhabit temperate and subtropical intertidal and shallow subtidal zone (Venkatraman & Mehta, 2019). However, *Porphyra* is rare in Indonesian waters, where only *Porphyra marcosii* grows wild, exclusively in Ambon (Loupatty, 2014). This limited availability underscores the need to identify alternative seaweed species suitable for nori production in Indonesia.

The production of nori-based products using local ingredients in Indonesia has been widely explored;

however, these attempts have not succeeded in replicating the quality and characteristics of commercial *Porphyra*-based nori (Ramadhan et al., 2022). Previous studies have experimented with various nori-like formulations, such as the addition of surimi (Pamungkas et al., 2023; Riyanto et al., 2014), blends of *U. lactuca* and *Gelidium* sp. (Erniati et al., 2018; Valentine et al., 2020), combinations of *U. lactuca* and *Gracilaria* sp. (Panjaitan et al., 2021; Sihono et al., 2023; Sinurat et al., 2022), drying techniques (Kurniawan et al., 2022; Pramudya et al., 2022; Utomo & Sinurat, 2022), and other food ingredients (Alaf et al., 2024; Ramadhan et al., 2022; Sihono et al., 2023). Among these studies, *Ulva* sp have been identified as favorable raw materials for nori-like product development due to their year-round availability, rapid growth rate, relatively high protein content compared to other seaweed genera, and morphological similarity to *Porphyra* (Harsha et al., 2023; Pari et al., 2025).

However, although *U. lactuca* has been utilized to produce nori-like products with comparable physical characteristics, comprehensive flavor characterization-particularly with respect to taste-active compounds

and aroma volatiles—remains limited. Flavor, which encompasses both taste and aroma, is a key factor in food product quality (Kawashima et al., 2018) and is essential for replicating the distinctive sensory attributes of commercial nori. The traditional flavor of nori is marked by amino acids such as glutamic acid, alanine, aspartic acid, and glycine (Kawashima et al., 2018; Mouritsen et al., 2019), along with inosinate and guanylate, while unsaturated fatty acids such as eicosapentaenoic acid (EPA) also contribute (Coleman et al., 2022; Nisizawa et al., 1987). Furthermore, volatile compounds such as acetaldehyde, isobutyraldehyde, and sulfur compounds are crucial for the characteristic aroma of nori (Arasaki & Arasaki, 1983; Milinovic et al., 2020). Moreover, a recent report Sinurat et al., (2023) suggests that specific amino acids in *U. lactuca* contribute to the formation of these volatile compounds, thereby influencing the product's overall aroma and consumer acceptance. Despite these insights, the flavor components in nori-like products, particularly in alternative seaweed species, have not been sufficiently explored, presenting a significant research gap for developing a nori-like product that mimics not only the texture and appearance but also the distinctive flavor of traditional nori.

The flavor of nori-like products from *Ulva lactuca* is limited, requiring enhancement with flavor-rich ingredients. Fermented products, containing diverse microorganisms, develop new flavors and improve food quality (Han et al., 2023; Lin et al., 2021). Their volatile organic compounds (VOCs)—alcohols, esters, acids, ketones, and sulfur compounds—significantly shape aroma and taste (van Wyk, 2024). In Indonesia, fermented products are mainly animal-based and use lactic acid bacteria (LAB), with seven distinct types identified (Mulyani et al., 2023). *Terasi* and *rusip* share flavor components with nori, making them promising for flavor enhancement.

Terasi, a fermented shrimp paste, and *rusip*, an anchovy-based fish sauce, are traditional Indonesian aquatic products with strong development potential. *Terasi* contains 31.61% protein and amino acids including glutamic acid (57.88 mg/g protein), alanine (23.54 mg/g protein), aspartic acid (46.50 mg/g protein), and taurine (21.48 mg/g protein) (Sumardianto et al., 2023). Its volatiles include 2,3-butanedione, 3-pentanone, tetramethylpyrazine, and ethyl acetate (Li et al., 2023). *Rusip* ranges from light brown to dark gray, with a sweet, sour, salty aroma typical of fermented fish, used as seasoning. Its umami taste derives from glutamic acid (2.07 mg/g protein), aspartic acid (1.39 mg/g protein), and glycine (0.57 mg/g protein) (Koesoemawardani, 2007; Koesoemawardani et al., 2018).

The flavor engineering of nori-like products derived from *Ulva lactuca* is critical to achieving sensory profiles comparable to those of commercial nori. Fermented

products such as *terasi* and *rusip* are rich in diverse microorganisms and volatile compounds, including alcohols, esters, acids, ketones, and sulfur compounds, making them promising sources for flavor enhancement (Han et al., 2023; van Wyk, 2024). However, comprehensive analysis of the volatile components and sensory profiles of *U. lactuca*-based nori-like products remains limited. Addressing this research gap is essential to overcoming the challenges associated with developing high quality, locally sourced nori-like products. Therefore, this study aimed to investigate the effects of *terasi* and *rusip* addition on the sensory profile and volatile composition of *U. lactuca*-based nori-like products and to identify formulations with the highest sensory acceptance

Material and Methods

Materials and Equipments

Dried *Ulva lactuca* was commercially sourced from PT Razindo Global Nusantara (Lombok, Indonesia) and met food safety standards per the supplier's Certificate of Analysis, with no detectable heavy metals (Pb, Hg, Cd, As). Commercial nori sheets were purchased from the Japanese domestic market. Agar powder, *terasi* (fermented *Acetes* shrimp paste with salt), and *rusip* (anchovy, palm sugar, and salt) were obtained from Sodap (Bagan Siapi-api, Indonesia) and Tiga Bintang (Pangkalpinang, Indonesia), respectively. Additional ingredients included salt (Dolphin, Indonesia), palm oil (Bimoli, Indonesia), sesame oil (Lee Kum Kee, Indonesia), glycerol, and distilled water. Equipment used comprised a freezer (RSA CF-1200), digital scale (Joil, Tangerang, Indonesia), blender (Philips HR2115), cooking pot (Maspion), stirring utensils, dehydrator (GETRA FD-30, China), and a custom acrylic mold for nori production.

Amino acid profiles were analyzed by ultra-performance liquid chromatography (UPLC-PDA, Milford, USA). Volatile compounds were assessed using headspace gas chromatography-mass spectrometry (HS-GCMS; Thermo Scientific Trace 1310 GC, Waltham, MA, USA). Texture was measured with a TA.XT Plus Texture Analyzer, and color was evaluated using a digital color analyzer (Xiaomi Poco).

Methods

Characterization of raw material

The raw materials used in the production of nori-like products, namely *Ulva lactuca*, *terasi*, and *rusip*, were characterized to determine their chemical compositions. The dried *U. lactuca* was transported from Lombok to Bogor in double-layer nylon and plastic packaging under ambient conditions. Upon arrival at IPB University, the

samples were re-sorted to remove visible impurities, cleaned, and stored under frozen conditions until further use. Prior to analysis, the dried seaweed was thawed, rinsed with tap water to remove surface debris, and rehydrated in distilled water at a ratio of 1:2 (w/v) for 6 h as part of the preparation process, adopted from the previous research conducted by Valentine et al., (2020) with slight modification on water base ratio. After rehydration, excess water was drained, and the material was used for subsequent chemical analysis and formulation. The shrimp paste (*terasi*) used in this study was a commercial “Sodap” brand product, while *rusip* was obtained from the “Tiga Bintang” brand originating from Bangka Belitung Province, Indonesia.

Nori-like formulation

The addition of *terasi* and *rusip* was divided into two groups: Nori-like product enriched with *Terasi* and Nori-like product enriched with *Rusip*, with concentrations of 1%, 2%, 3%, and 4%. These percentages represent the proportion of *terasi* or *rusip* relative to the total weight of the nori slurry (w/w). The nori-like formulation refers to a modified version of the method proposed by (Sihono et al., 2023). The nori formulation comprised *U. lactuca* (30%), agar (0.15%), cooking oil (0.5%), sesame oil (0.5%), salt (0.5%), glycerol (2%), sodium metabisulfite (0.2%), and water, which were blended into a slurry. Ingredient percentages in the initial formulation were expressed on a total slurry weight basis. The homogeneous mixture was subsequently poured into acrylic nori molds, each of which was lined with a 22 × 22 cm² food-grade, non-stick polytetrafluoroethylene (PTFE) sheet. The nori slurry was subsequently dehydrated at 60°C for 6 h. The nori-like *U. lactuca* was then roasted for 2 min at 150°C. The final product was packaged in aluminum foil plastic packaging with silica gel and tightly sealed using a heat-sealer. The optimal formulation was determined based on hedonic sensory evaluation according to (SNI, 2022), and sensory attribute assessment was conducted using Quantitative Descriptive Analysis (QDA) as described by (Kurnia, 2010). Sensory evaluation was conducted using a nine-point hedonic scale, where 1 corresponded to ‘dislike extremely’ and 9 corresponded to ‘like extremely’.

The attributes evaluated included the aroma and taste of nori-like products. The panelists assessed the intensity of five taste attributes (sweetness, saltiness, sourness, bitterness, and umami) and five aroma attributes (roasted, savory, sour, bitter, and fishy).

Characterization of Nori-like

The best nori-like *Ulva lactuca* formulation for each group was characterized and compared with commercial nori. Parameters tested included proximate

analysis (AOAC, 2005) - moisture, ash, protein, fat, and carbohydrate content, amino acid profile (18-5-17/MU/SMM-SIG), volatile component analysis (Sithersingh & Snow, 2021), texture profile following the methodology by Sajida (2016), and color profile based on (Ramadhan et al., 2024).

Amino acid analysis

Amino acid analysis was performed using the 18-5-17/MU/SMM-SIG method (UPLC-PDA). A standard amino acid concentration, along with an internal standard, was prepared for the analysis. The sample was weighed and subjected to hydrolysis with hydrochloric acid (HCl). The resulting hydrolysate was transferred to a 50 mL volumetric flask, and distilled water was added to the calibration mark. The test solution was subsequently filtered through a 0.2 µm syringe filter, and the filtrate was collected for further analysis. The internal standard was then added, and derivatization was performed prior to injection into the UPLC system. The UPLC conditions were as follows: an ACCQ-Tag Ultra C-18 column was used, with the amino acid standard sourced from SIGMA-ALDRICH (AAS18-10x1mL). The analysis was conducted at a temperature of 49°C, with a flow rate of 0.7 mL/min. The detection was performed using a Photodiode Array (PDA) detector at a wavelength of 260 nm, and the injection volume was set at 1 µL.

Screening volatile compounds

Samples were analyzed using headspace gas chromatography-mass spectrometry (HS-GC-MS) with electron ionization (EI), following the principles described by Sithersingh & Snow (2021). Small sample pieces (100 µL) were placed in 20 mL vials and incubated at 135 °C for 15 minutes. Chromatographic separation was performed on an HP-5MS UI column (30 m × 0.25 mm, 0.25 µm) using helium as the carrier gas at 1 mL/min. The temperature program began at 40 °C (1 min), ramped to 150 °C over 23 minutes, then increased to 250 °C at 35 minutes, with a total runtime of 38 minutes. Ionization was conducted in positive EI mode at 230 °C, scanning masses from 10 to 400 amu with a 0.2-second scan time. Data were analyzed using NIST libraries and Cromeleon 7 software.

Data Analysis

Nonparametric hedonic sensory data, were analyzed using the Kruskal-Wallis test. The characteristics of the nori-like products were analyzed using Analysis of Variance (ANOVA) with a Completely Randomized Design (CRD) and a 95% confidence interval ($\alpha = 0.05$). In cases where significant differences were observed, further analysis was conducted using Duncan's multiple range test.

Results and Discussion

Characterization of Raw Materials

The raw materials were characterized to determine their proximate compound content present in the raw material, which may affect the final result of the nori. The parameters used in the characterization included proximate analysis, amino acid profile, and volatile components. The proximate results of raw materials for the manufacture of nori-like products are listed in Table 1.

Based on the proximate analysis, the protein content of *U. lactuca* is 19.73%, which is lower than that of *P. tenera*, with a protein content of 36.88% (Hwang et al., 2013). The differences in proximate composition

between *U. lactuca* and *P. tenera* can be attributed to the distinction between green and red seaweed species. According to (Cherry et al., 2019), red seaweed contains protein levels ranging from 0.67% to 45.0% (w/w), while green seaweed contains protein levels between 3.42% and 29.80% (w/w). Variations in protein content also affect the amino acid composition of seaweeds.

Terasi exhibited the highest protein (48.08%) and ash content (45.19%) with low moisture (2.20%), reflecting its concentrated fermented shrimp paste nature and exceeding the minimum protein requirement of SNI 2716:2016. In contrast, *rusip* showed high moisture (64.98%), moderate protein (17.19%), and lower ash and fat contents, consistent with its paste-like fermented fish form. Nurhamzah et al., (2021) reported *rusip* protein

Table 1. Proximate raw materials.

Parameters (%)	<i>U. lactuca</i>	<i>Terasi</i>	<i>Rusip</i>
Protein	19.73±0.08	48.08±0.18	17.19±0.05
Moisture	28.55±0.24	2.20±0.17	64.98±0.37
Ash	26.78±0.04	45.19±0.22	13.41±0.13
Fat	0.51±0.01	4.01±0.09	1.12± 0.05
Carbohydrates (by difference)	24.44±0.20	0.53±0.15	3.32±0.39

Table 2. The amino acids profile of the raw materials.

Parameter	<i>Ulva lactuca</i>		<i>Terasi</i>		<i>Rusip</i>	
	Total	%	Total	%	Total	%
Essential Amino Acids (mg/100 g protein)						
Threonine	709.58	5.41	2,641.43	4.13	3,549.61	5.34
Valine	963.00	7.34	3,889.35	6.08	4,829.79	7.26
Methionine	101.37	0.77	1,247.92	1.95	2,094.85	3.15
Isoleucine	658.90	5.02	4,305.32	6.73	4,015.13	6.04
Leucine	1,064.37	8.11	6,426.79	10.05	5,993.60	9.01
Phenylalanine	1,115.05	8.49	3,057.40	4.78	2,909.51	4.37
Histidine	456.16	3.47	2,391.85	3.74	1,512.95	2.27
Lysine	861.63	6.56	5,199.67	8.13	6,982.83	10.50
Non- Essential Amino Acids (mg/100 g protein)						
Aspartic acid	1,621.90	12.36	6,364.39	9.95	6,982.83	10.50
Serine	709.58	5.41	2,287.85	3.58	2,734.94	4.11
Glutamic acid	1,419.16	10.81	11,980.03	18.73	12,336.34	18.55
Glycine	709.58	5.41	4,492.51	7.02	3,898.75	5.86
Alanine	1,013.68	7.72	4,513.31	7.05	4,771.60	7.17
Tyrosine	506.84	3.86	1,788.69	2.80	1,047.43	1.57
Arginine	1,216.42	9.27	3,390.18	5.30	2,851.32	4.29
Total EAA	5,930.06	45.17	29,159.73	45.58	31,888.27	47.94
Total NEAA	7,197.16	54.83	34,816.97	54.42	34,623.22	52.06
Total amino acid	13,127.22		63,976.71		66,511.49	

content ranging from 12.20% to 15.43%, influenced by raw material quality. Variations in protein content affect amino acid composition, detailed in Table 2.

The dominant amino acids in the raw materials were glutamic acid, aspartic acid, arginine, and leucine, with glutamic acid being the most abundant: 10.81% in *Ulva lactuca*, 18.73% in *terasi*, and 18.55% in *rusip*. These amino acids play a key role in developing the umami flavor, which enhances overall taste and is critical in food formulation (Machado et al., 2020; Charve et al., 2018). Umami results from the interaction of glutamic acid with salt, while amino acids such as alanine, serine, and glycine contribute sweetness. Conversely, arginine, histidine, leucine, and methionine are associated with bitterness (Lin et al., 2018; Zhang et al., 2012). Additionally, volatile compounds further enhance the sensory characteristics of food products, complementing the amino acid-driven flavor profile.

The volatile component analysis revealed four peaks in *U. lactuca*, 34 peaks in *terasi*, and 20 peaks in *rusip* (Figure 1). The dominant compound in *U. lactuca* was

dimethylaminomethyl-isopropyl sulfide (41.39%), a sulfur-containing compound associated with marine and savory aroma notes, which enhance taste perception through aroma–taste interactions. In *terasi*, the primary volatile was 2-methylpropanal (34.94%), contributing wine, solvent, and bitter flavors (Kleekayai et al., 2016). Aldehydes like 2-methylpropanal are known to enhance roasted and savory aromas, intensifying umami and flavor complexity. The shrimp used in *terasi* production is rich in glutamic acid, proline, arginine, glycine, alanine, and leucine (Peralta et al., 2008; Pongsetkul et al., 2022). In *rusip*, the dominant volatile was 3-methylbutanal (30.89%), contributing an acidic flavor typical of fermentation. Compounds such as 2-methylbutanal and 3-methylbutanal, produced via microbial biosynthesis of leucine, valine, and isoleucine, are key contributors to the aroma of fermented products like soy sauce (Steinhaus & Schieberle, 2007). These volatiles shape the characteristic aroma and influence the taste and acceptability of fermented foods. Compared with commercial nori, the formulated nori-like products shared several key

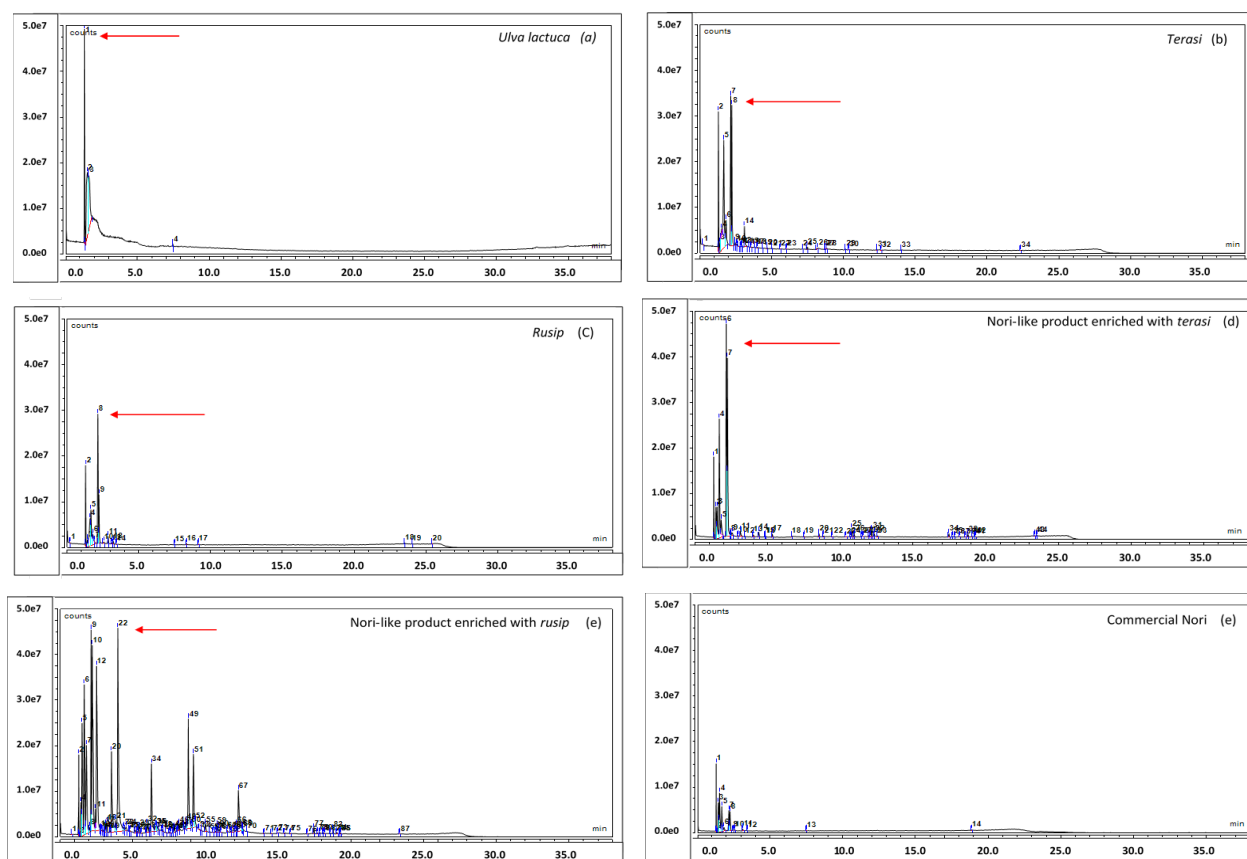


Figure 1. Total ion chromatograms (TIC) of volatile compounds identified in (a) *Ulva lactuca*, (b) *terasi*, (c) *rusip*, (d) nori-like product enriched with *terasi*, (e) nori-like product enriched with *rusip*, and (f) commercial nori. The red arrows indicate the retention time region with dominant volatile peaks corresponding to major aroma-contributing compounds.

savory and marine volatile compounds, though relative abundances differed. This overall alignment supports the feasibility of the formulation while indicating scope for further optimization.

Sensory Evaluation of Nori-Like Products

Hedonic sensory evaluation assigns scores to each group of nori-like products based on parameters such as color, aroma, taste, texture, and overall preference. The results of sensory testing for the *U. lactuca* nori-like group are presented in Figure 2.

Sensory evaluation of the Nori-like product enriched with *Terasi* indicated that 2% *terasi* addition was the best treatment, achieving the highest scores for aroma and overall acceptability. Panelists rated the overall parameter at 2% *terasi* addition as 8.6 ("like very much"), whereas the 3% and 4% *terasi* additions received the lowest scores. Umami and salty flavors intensified with higher *terasi* concentrations. These findings are consistent with Suparmi et al., (2021), who reported that increasing rebon shrimp flour in macaroni led to progressively less desirable flavor profiles.

The hedonic sensory evaluation of nori-like products with added *rusip* yielded significant results. The concentration of *rusip* had a notable effect on the taste, texture, and overall parameters of the *rusip* nori-like product. The best treatment for the nori-like with *rusip* addition was the 3% *rusip* formula. The scores obtained for the 3% *rusip* addition ranged from 7.3 to 8.6, showing a significant difference from other treatments. Higher concentrations of *rusip* in the nori-like product resulted in an overly intense flavor, which was less preferred by the panelists. *Rusip* is characterized by a sour taste, with a sour aroma and slight sweetness (Puspita et al., 2024).

Quantitative descriptive analysis (QDA) was conducted to evaluate the intensity of ten sensory attributes—sweetness, saltiness, sourness, bitterness, umami, and the aromas of roasted, savory, sour, bitter, and fishy notes—in the nori-like samples. Nori-like product enriched with *Terasi* samples were characterized by a dominant salty taste with moderate umami and bitterness, whereas nori-like product enriched with *rusip* samples exhibited a pronounced umami taste accompanied by moderate sweetness, saltiness, and bitterness. Regarding aroma, Nori-like product enriched with *Terasi* samples

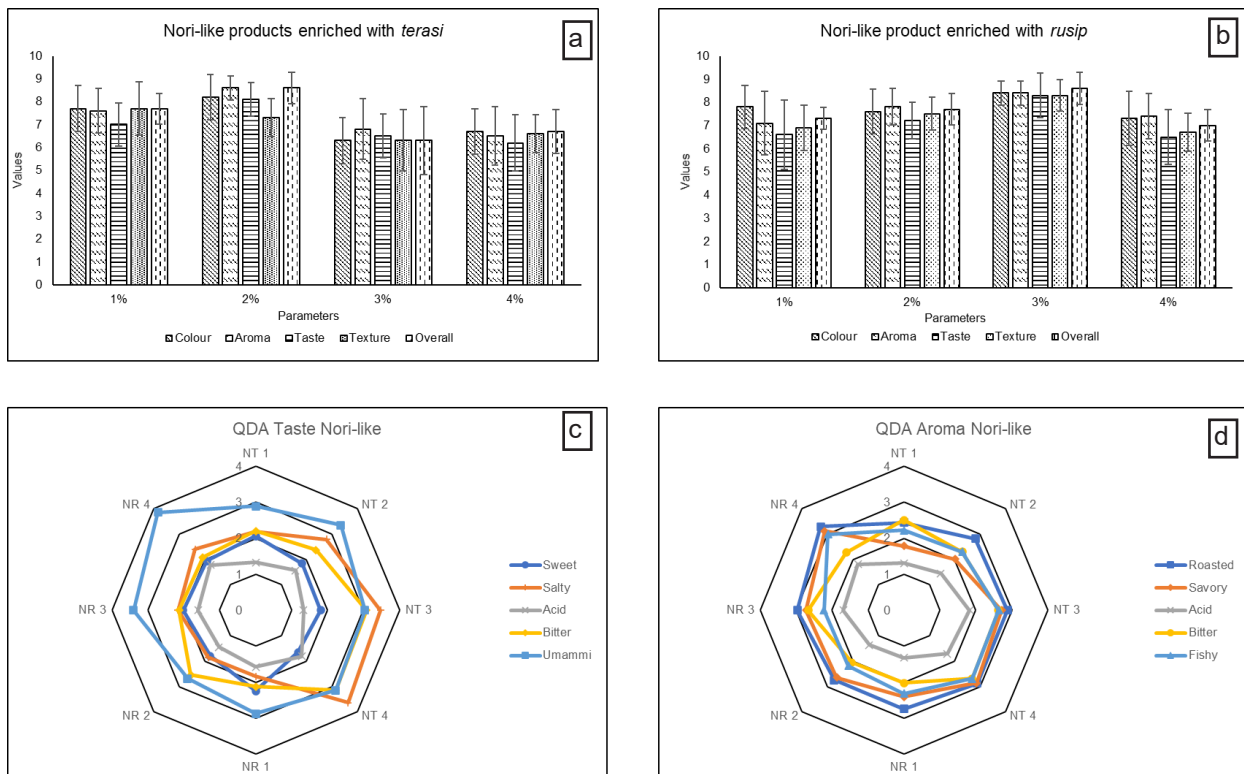


Figure 2. Evaluation sensory Nori-like. a: hedonic Nori-like product enriched with *Terasi*, b: hedonic Nori-like product enriched with *Rusip*, c: QDA taste nori-like, and d: Aroma nori-like. NT 1: Nori-like product enriched with *Terasi* 1%, NT 2: Nori-like product enriched with *Terasi* 2%, NT 3: Nori-like product enriched with *Terasi* 3%, NT 4: Nori-like product enriched with *Terasi* 4%, NR 1: Nori-like product enriched with *Rusip* 1%, NR 2: Nori-like product enriched with *Rusip* 2%, NR 3: Nori-like product enriched with *Rusip* 3%, NR 4: Nori-like product enriched with *Rusip* 4%.

displayed moderate roasted, savory, and fishy notes, while nori-like product enriched with *rusip* samples showed moderate roasted, savory, and bitter notes. The roasted aroma detected across both formulations is likely attributable to the protein- and lipid-rich composition of *terasi* and *rusip*, which promotes Maillard-type reactions known to generate roasted aromatic compounds (Wang et al., 2022).

Characterization of Nori-like

The selected nori-like formulations were further characterized and compared with commercial nori as a control to evaluate the effects of *terasi* and *rusip* addition (Table 3). Protein contents of the Nori-like product enriched with *Terasi* and the Nori-like product enriched with *Rusip* were 18.25% and 15.38%, respectively, both

Table 3. Proximate, amino acid, color and texture Profile of nori-like product enriched with *Terasi*, Nori-like product enriched with *Rusip*, and commercial nori. Difference superscripts (a,b,c) within the same row indicates a significant difference ($p < 0.05$)

Parameters	Sample		
	Nori-like product enriched with <i>Terasi</i>	Nori-like product enriched with <i>Rusip</i>	Commercial Nori
Protein (%)	18.25 ± 0.25 ^c	15.38 ± 0.26 ^a	38.03 ± 0.67 ^d
Moisture (%)	2.46 ± 0.04 ^b	2.69 ± 0.04 ^c	6.42 ± 0.10 ^d
Ash (%)	22.00 ± 0.01 ^c	20.12 ± 0.03 ^b	12.56 ± 0.22 ^a
Fat (%)	10.27 ± 0.12 ^b	11.19 ± 0.17 ^c	3.615 ± 0.09 ^a
Carbohydrate (%)	47.04 ± 0.32 ^b	50.63 ± 0.10 ^d	39.38 ± 0.47 ^a
Total energy (kcal/100 g)	353.53 ± 0.78 ^b	364.69 ± 0.87 ^c	342.18 ± 0.04 ^a
Energy from fat (kcal/100 g)	92.39 ± 1.04 ^b	100.67 ± 1.49 ^c	32.54 ± 0.77 ^a
Amino acids (%)			
Threonine	4.48	4.22	5.17
Valine	5.27	6.67	6.00
Isoleucine	3.90	4.95	3.54
Leucine	8.42	9.52	9.03
Phenylalanine	5.81	5.63	5.19
Histidine	1.75	1.10	1.82
Lysine	5.77	7.12	5.71
Aspartic acid	12.39	9.63	10.53
Serine	5.80	5.44	4.15
Glutamic acid	14.18	12.13	14.31
Glycine	8.27	8.38	6.86
Alanine	9.29	10.67	12.03
Proline	5.78	8.43	5.96
Tyrosine	3.33	0.60	2.56
Arginine	5.57	5.50	7.15
Color profile (Difference superscripts (a,b,c) within the same row indicates a significant difference ($p < 0.05$))			
<i>L</i> *	37.62 ± 3.49 ^a	32.84 ± 8.56 ^a	38.86 ± 3.32 ^a
<i>a</i> *	-6.15 ± 0.35 ^b	-6.38 ± 0.89 ^b	-5.94 ± 0.53 ^b
<i>b</i> *	17.95 ± 1.62 ^{ab}	18.43 ± 3.37 ^b	14.62 ± 1.06 ^a
Texture profile			
Film burst strength (g force)	181.16	288.67	771.90
Distance at burst (mm)	-0.33	1.21	-1.53

lower than that of commercial nori (38.03%). This is consistent with the value reported for *Porphyra* sp. nori (42.99%) by Admassu et al., (2018). The discrepancy reflects differences in raw material source, as the nori-like products were derived from *Ulva lactuca*, whereas commercial nori is derived from *Porphyra* spp.

Proximate composition (moisture, ash, fat, and carbohydrate) and total energy content also differed between the nori-like products and commercial nori (Table 3), further reflecting the compositional distinctions arising from the different raw materials and formulations used.

The amino acids predominantly found in nori-like products and commercial nori include glutamic acid (12.13-14.31%), aspartic acid (9.63-12.39%), alanine (9.29-12.03%), and leucine (8.42-9.03%). The glutamic acid content in the Nori-like product enriched with *Terasi* was slightly lower than that in commercial nori, with a value of 14.31%. A high glutamic acid and aspartic acid content can significantly enhance the flavor of nori-like products. The active flavor in nori is influenced by the composition of amino acids such as glutamic acid, alanine, aspartic acid, and glycine (Araki et al., 1997; Kawashima et al., 2018; Yoshie et al., 1993).

Visually (Figure 3), the nori-like samples exhibited a dark green to yellowish-green hue comparable to commercial nori. The Nori-like product enriched with *Terasi* and the Nori-like product enriched with *Rusip* displayed darker coloration but lacked the glossy surface layer characteristic of commercial nori. Nori is visually graded into Grade A and Grade B, with Grade A characterized by a darker color attributable to lipophilic pigments, including chlorophyll, carotenoids, and phycobilins (Tanaka et al., 2016). High-quality nori is further distinguished by a deep black color, glossy appearance, and smooth, non-porous surface (Ogawa et al., 1991).

Color parameters were quantified from digital images captured using a Poco smartphone, and lightness (L^*), redness–greenness (a^*), and yellowness–blueness (b^*) values were extracted using the CIE Lab* color space, where L^* ranges from 0 (black) to 100 (white), positive a^* indicates redness and negative a^* indicates greenness, and positive b^* indicates yellowness and negative b^* indicates blueness (Fadlilah et al., 2022). L^* values ranged from 32.84–41.21, with no significant difference between nori-like and commercial samples ($p > 0.05$), indicating comparable brightness. Similarly, a^* values of *terasi*- and *rusip*-enriched samples did not differ significantly from commercial nori ($p > 0.05$). Overall, the *terasi*-enriched product most closely resembled commercial nori across all color parameters.

Texture analysis revealed pressure strength values ranging from 181.16 g (nori-like enriched with *terasi*) to 288.67 g (nori-like enriched with *rusip*), both markedly lower than commercial nori (771.90 g). Lower pressure strength reflects a more brittle, rigid film structure, likely resulting from differences in raw material composition and processing conditions affecting mechanical properties. Pressure distance, representing the maximum probe displacement before rupture, indicates elasticity when positive and shrinkage when negative. Nori-like enriched with *rusip* samples showed positive values (1.21 mm), reflecting elastic, chewy characteristics, whereas nori-like enriched with *terasi* and commercial nori samples showed negative values (−0.33 and −1.53 mm, respectively), indicating shrinkage and brittleness. These differences are attributable to variation in raw material composition, drying method, and binder type. (Pires et al., 2024).

The volatile component analysis for nori-like and commercial nori samples revealed common volatile components, including 2-methylpropanal, 2-methylbutanal, and 3-methylbutanal. The volatile

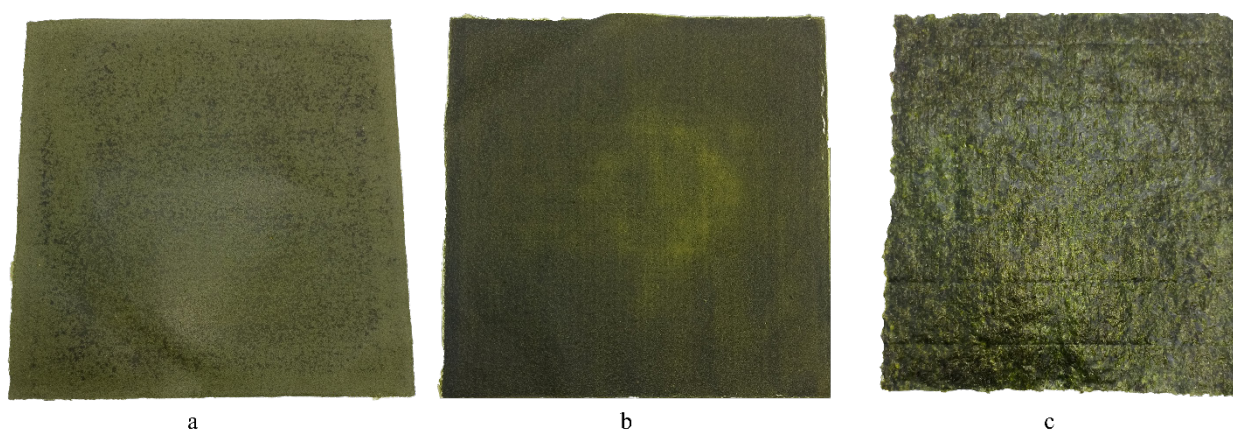


Figure 3. Visual representation of Nori-like. a: Nori-like product enriched with *Terasi*; b: Nori-like product enriched with *Rusip*; c: commercial nori

component, 2-methylpropanal, was described as having a strong, pungent, aldehydic, and floral aroma. The flavor description of 2-methylbutanal included sulfur, vegetables, green cabbage, and fishy notes. In contrast, the flavor description of 3-methylbutanal was characterized by smooth, aldehydic, chocolate, peach, and fatty aromas (The Good Scent Company, 2021). The volatile components in nori-like samples made with the green seaweed species *U. lactuca* showed a greater number of volatile components than commercial nori, which uses the red seaweed species *Porphyra* sp. A higher number of volatile components is typically found in green seaweed compared to brown or red seaweed (Narain, 2018). Common flavor descriptions associated with seaweed include marine, fishy, and seafood notes. Carboxylic acids contribute flavors such as root, honey, and spice aromas, while esters and sulfur compounds produce green grass and straw-like aromas. Amines and pyridines generate marine, fish, fatty, and seafood-related flavors (López-Pérez et al., 2017). Based on Shu & Shen (2012) odor-active in nori most from pyrazines have notes roasted, coffee and linked to head reactions of sugar and amino acid, which explained roasted nori had strong odor nutty and burnt.

Based on the number of volatile components detected in all nori-like samples compared to commercial nori, the flavor enrichment of nori-like with the addition of traditional Indonesian fermented products can enhance the flavor profile of nori-like. Nori-like product enriched with *Terasi* and nori-like mixtures showed a three-fold increase, whereas Nori-like product enriched with *Rusip* exhibited a six-fold increase in the number of volatile components compared to commercial nori. This nori-like flavor enrichment offers a new and distinctive taste

Conclusion

The optimal formulations for nori-like products were identified as 2% *terasi* and 3% *rusip*, respectively. Sensory profile confirmed that both formulations produced products with a pronounced umami flavor and a moderately roasted aroma. These flavor attributes were supported by amino acid profiles rich in glutamic acid, aspartic acid, glycine, and leucine. Volatile compound screening revealed a threefold increase in the number of aroma-active compounds in the *terasi*-enriched variant and a sixfold increase in the *rusip*-enriched variant compared to commercial nori. These findings demonstrate that traditional Indonesian fermented products can significantly enhance the flavor complexity of *U. lactuca*-based nori analogs, offering a promising strategy for local, culturally relevant seaweed product development.

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