

Effect of Drying Time on the Quality of Nori Produced from *Kappaphycus alvarezii* Seaweed with the Addition of *Moringa oleifera* Leaves

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Article Information	ABSTRACT
Article History Received : July 04, 2026 Revised : July 19, 2026 Published : July 24, 2026	The increasing demand for healthy and practical food products has encouraged the development of nori produced from <i>Kappaphycus alvarezii</i> as an alternative to conventional seaweed sheets. However, drying time is a critical processing factor influencing the sensory, physical, and functional quality of the final product. This study aimed to determine the optimum drying time for producing high-quality nori supplemented with <i>Moringa oleifera</i> leaves. A completely randomized design was applied using three drying times (13, 14, and 15 h), selected based on previous studies indicating that this range provides sufficient moisture removal while minimizing quality deterioration during nori production. The evaluated parameters included sensory characteristics, physical properties, and antioxidant activity. Drying time significantly affected ($p < 0.05$) all evaluated parameters. The 14 h treatment produced the highest sensory acceptance, with appearance (8.02), texture (8.24), taste (8.48), aroma (8.40), and color (8.36), closely resembling commercial nori. This treatment also provided balanced physical properties (thickness 0.23 mm and tensile strength 12.18 N) and moderate antioxidant activity ($IC_{50} = 137.27$ ppm), which was superior to that of commercial nori (199.25 ppm). These findings demonstrate that drying for 14 h is the optimum condition for producing high-quality nori from <i>Kappaphycus alvarezii</i> and provides a practical processing reference for seaweed-processing industries and small-scale nori manufacturers utilizing locally available raw materials.
Keywords: <i>Antioxidant activity;</i> <i>Drying time;</i> <i>Kappaphycus alvarezii;</i> <i>Nori;</i> <i>Sensory quality.</i>	

INTRODUCTION

Indonesia is a maritime nation, with approximately 70% of its territory consisting of marine waters, providing substantial potential for the development of marine aquaculture (Syafitri et al., 2022). The country possesses approximately 6.4 million km² of marine area and 110,000 km of coastline. Combined with its tropical climate, these conditions are highly favorable for the cultivation of various seaweed species (Yusran et al., 2021). Seaweed is one of Indonesia's leading fishery export commodities and is predominantly exported in dried form (Arthatiani et al., 2021). According to the International Trade Centre (ITC), the global seaweed market was valued at approximately USD 2.8 billion in 2021. Indonesia has become one of the world's leading seaweed producers and exporters, contributing significantly to the global seaweed market (Cai, 2021).

Seaweed can be processed into a wide variety of food products, one of which is nori (Tianasari et al., 2018). Traditionally, nori is a dried edible seaweed sheet produced from *Porphyra* spp. (Loupatty, 2014). In Japanese cuisine, nori is commonly used as a garnish, seasoning, accompaniment to rice, and an ingredient in various snack foods such as *senbei* (Lalopua, 2017).

Commercial nori is generally manufactured from *Porphyra* species, including *Porphyra pseudolinearis* Ueda (Iwanori) and *Porphyra yezoensis* Ueda (Loupatty, 2014). However, the availability of *Porphyra* in Indonesia is limited, occurring only seasonally in the waters surrounding Ambon Island, Maluku, and for relatively short harvesting (Fransiska et al., 2022). Consequently, alternative seaweed species suitable for nori production are required. One promising alternative is *Kappaphycus alvarezii*, which is widely cultivated and abundantly available throughout Indonesia.

Kappaphycus alvarezii is one of the most economically important seaweed species cultivated in Indonesia and has considerable market potential (Soejarwo & Yusuf, 2018). This species contains various essential nutrients, including calcium, dietary fiber, and iron (Anggraini, 2018). Moreover, *K. alvarezii* is an important source of carrageenan, containing approximately 62–68% carrageenan on a dry weight basis, which functions as a natural binding agent and makes it suitable as a raw material for nori production (Devi et al., 2022). The incorporation of *Moringa oleifera* leaves can further enhance the nutritional quality of nori because of their high antioxidant content. In addition, moringa leaves contribute a more attractive green color to the final product (Wulansari et al., 2020b).

The rapid growth of Japanese and Chinese restaurants serving ready-to-eat meals in Indonesia has increased domestic demand for nori by approximately 80% (Loupatty, 2014). Consequently, strengthening domestic nori production has become increasingly important to reduce dependence on imported products. One seaweed-processing company supplying *K. alvarezii* is CV. Sari Mutiara Abadi, located in Lawang, East Java, with its central laboratory situated in Karanglo, Malang. However, the company does not currently produce nori. Therefore, this study is expected to contribute to the development of an acceptable nori product utilizing locally available raw materials. Establishing efficient domestic production of nori from Indonesian seaweed, together with determining the optimum drying conditions, is expected to gradually reduce reliance on imported nori.

Drying is one of the most critical stages in nori processing because it directly influences the physicochemical and sensory properties of the final product. Drying is defined as the process of removing most of the moisture from a material through the application of thermal energy (Stevani et al., 2019). The duration of drying is expected to affect the quality characteristics of nori. Therefore, this study aimed to evaluate the quality of nori produced from *Kappaphycus alvarezii* supplemented with *Moringa oleifera* leaves and to investigate the effect of drying time on the quality characteristics of the resulting nori.

MATERIALS AND METHODS

The study was conducted at three laboratories in Indonesia. Organoleptic evaluation and thickness measurements were performed at the Central Laboratory of CV. Sari Mutiara Abadi (Malang, East Java). Tensile strength and color analyses were conducted at the Laboratory of Life Science (LSIH), Universitas Brawijaya, while antioxidant activity was determined at the Central Laboratory of Universitas Muhammadiyah Malang.

Nori Preparation and Drying

Nori was prepared following Pade, (2022) with modifications. Nori sheets were prepared from *Kappaphycus alvarezii* seaweed and *Moringa oleifera* leaves, which were washed and processed according to the experimental treatments. The raw materials were homogenized, mixed with seasonings, and heated with continuous stirring until a thick paste was formed. The paste was then spread into thin sheets, dried to obtain dehydrated nori, cut into uniform sizes, and stored in airtight packaging prior to further analyses. Drying treatments of 13, 14, and 15 h were adopted from by Andriani et al., (2020) and Rahardjanto et al., (2019) to determine the optimum drying time for producing high-quality dried nori.

Organoleptic Evaluation of Raw Materials

The organoleptic quality of dried *Kappaphycus alvarezii* was evaluated according to SNI 2690:2018) (BSN, 2015) by six trained panelists assessing appearance and texture. Analyses were conducted in triplicate, and results were expressed as mean values with 95% confidence intervals.

Hedonic Evaluation of Nori

Sensory acceptance of the nori was evaluated by 30 untrained panelists using a nine-point hedonic scale (Lalopua, 2017). Appearance, aroma, texture, taste, and color were assessed in triplicate.

Physical Analysis

Nori thickness was measured using a 0.001-mm micrometer at five locations per sheet following Unsa & Paramastri, (2018). Tensile strength was determined using a Universal Testing Machine according to Indriani et al., (2021). Color parameters (L^* , a^* , and b^*) were measured with a Konica Minolta CR-400 Chroma Meter (CIE system) following Riyanto et al., (2015).

Antioxidant Activity Assay

Antioxidant activity was determined using the DPPH radical scavenging assay (Wulansari et al., 2022; Fitriana et al., 2015). Briefly, 0.2 g of sample was extracted with distilled water, filtered, reacted with DPPH solution, incubated in the dark for 30 min, and measured at 517 nm using a UV-Vis spectrophotometer. Antioxidant capacity was expressed as the IC_{50} value.

Statistical Analysis

Physical and antioxidant data were expressed as mean $\pm$ standard deviation and analyzed using one-way ANOVA followed by Tukey's HSD test ($\alpha = 0.05$). Hedonic data were analyzed using the Kruskal-Wallis test followed by the Mann-Whitney U test for pairwise comparisons when significant differences were detected ($p < 0.05$). All analyses were performed using IBM SPSS Statistics version 27.

RESULTS AND DISCUSSION

The nori produced under different drying time treatments exhibited distinct visual characteristics. Variations in drying duration affected the appearance of the nori sheets as a result of moisture removal during the drying process. The visual differences among the nori samples subjected to different drying times are presented in **Figure 1**.

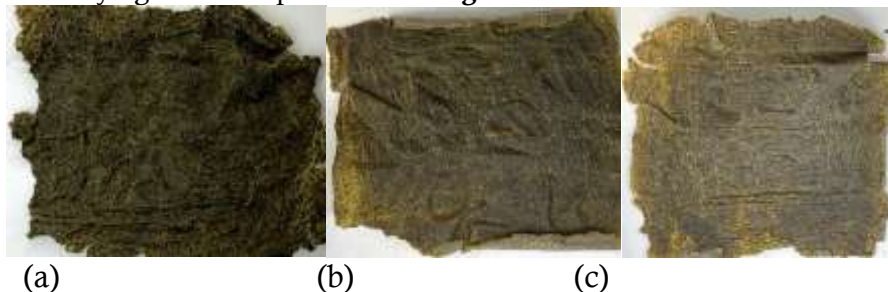


Figure 1. Nori sheets dried for (a) 13 h, (b) 14 h, and (c) 15 h.

From a processing efficiency perspective, the 14 h drying treatment represents the optimum operating condition because it achieved the best balance between product quality and processing time. Although direct energy consumption was not measured in this study, drying duration is closely associated with energy requirements, with longer drying periods generally resulting in higher energy consumption and lower production efficiency. Compared with the 15 h treatment, reducing the drying time by 1 h improved process efficiency while maintaining superior sensory acceptance, balanced physical properties, and moderate antioxidant activity. Conversely, shortening the drying time to 13 h reduced processing time but resulted in inferior sensory quality and less desirable physical characteristics, indicating incomplete moisture removal. Therefore, extending the drying process beyond 14 h did not provide additional quality benefits sufficient to justify the extra processing time and likely higher energy demand. These findings suggest that a 14 h drying duration offers a practical compromise between product quality and production efficiency, making it a suitable processing condition for industrial applications and small- and medium-sized enterprises (SMEs) seeking to optimize productivity while minimizing processing costs.

Hedonic Evaluation of Nori

The results of the hedonic evaluation of nori subjected to different drying time treatments, including appearance, texture, taste, aroma, and color, are presented in **Table 1**. Statistical analysis showed that drying time had a significant effect ($p < 0.05$) on all hedonic attributes. Values followed by different superscript letters within the same column indicate significant differences among treatments according to the post hoc multiple comparison test.

Table 1. Hedonic evaluation of nori subjected to different drying time treatments.

Drying Treatment	Appearance	Texture	Taste	Aroma	Color
13 h	6.97 $\pm$ 0.07 ^a	6.40 $\pm$ 0.12 ^a	6.40 $\pm$ 0.09 ^a	6.23 $\pm$ 0.03 ^a	6.43 $\pm$ 0.03 ^a
14 h	8.02 $\pm$ 0.07 ^b	8.24 $\pm$ 0.04 ^b	8.48 $\pm$ 0.05 ^b	8.40 $\pm$ 0.07 ^b	8.36 $\pm$ 0.04 ^b
15 h	6.18 $\pm$ 0.02 ^c	6.09 $\pm$ 0.08 ^c	7.57 $\pm$ 0.03 ^c	7.13 $\pm$ 0.03 ^c	6.40 $\pm$ 0.03 ^{ac}
Commercial nori	8.32 $\pm$ 0.04 ^d	8.43 $\pm$ 0.03 ^{bd}	8.42 $\pm$ 0.02 ^{bd}	8.46 $\pm$ 0.05 ^{bd}	8.36 $\pm$ 0.02 ^{bd}

Note: Values are presented as **mean $\pm$ standard deviation**. Different superscript letters within the same column indicate significant differences among treatments ($p < 0.05$).

Hedonic Evaluation of Nori

The hedonic evaluation (**Table 1**) showed that drying time significantly affected ($p < 0.05$) the appearance, texture, taste, aroma, and color of the nori. The 14-h treatment produced the highest sensory scores across all attributes and most closely resembled the commercial product. High-quality nori is characterized by a thin sheet structure, a distinctive seaweed aroma, a salty taste, a flexible texture that can be rolled, and a dark green color (Castro et al., 2018). Hedonic evaluation was conducted to determine the panelists' degree of preference for the nori samples (Mulyani, 2016). Consumer preference scores are influenced by the subjective perceptions of the panelists, making panelist evaluation an important factor in sensory assessment (Valentine et al., 2020).

As shown in **Table 1**, the 14-h drying treatment produced the highest appearance score (8.02 ± 0.07 ; $p < 0.05$), indicating a more uniform and visually appealing surface than the 13- and 15-h treatments. Shorter drying likely resulted in incomplete moisture removal, whereas prolonged drying caused excessive shrinkage, reducing product appearance. The thickness of the nori sheets was influenced by drying duration. This observation agrees with the findings of (Riyanto et al., 2015), who reported that the thickness of imitation nori sheets was associated with the amount of myofibrillar protein solution as well as drying rate and drying duration. During heating, protein denaturation promotes molecular unfolding and exposes reactive groups on the polypeptide chains. Interactions among these reactive groups retain water and form a gel network. As water separates from the coagulated proteins, protein precipitation occurs, resulting in the formation of a continuous film sheet (Riyanto et al., 2015).

The 14-h treatment produced the highest texture score (8.24 ± 0.04 ; **Table 1**), indicating a compact, non-rigid structure. In contrast, 13-h drying resulted in a softer texture due to higher moisture content, whereas 15-h drying produced an excessively hard texture. These differences are associated with the carrageenan content of *Kappaphycus alvarezii* and drying conditions. Prolonged heating promotes carrageenan extraction, as indicated by increased solution viscosity resulting from gel formation (Lalopua, 2018). Gelation involves the cross-linking of polymer chains to form a continuous three-dimensional network with elastic and rigid properties, thereby contributing to the characteristic texture of nori (Herawati, 2018).

The highest taste score (8.48 ± 0.05) was also obtained from the 14-h drying treatment, indicating the development of a desirable flavor profile through optimal concentration of flavor-active compounds without excessive thermal degradation. Both insufficient and excessive drying reduced panelist acceptance of taste. The savory flavor of nori is influenced by the ingredients used during processing (R. Widyastuti et al., 2021). Taste is one of the most important sensory attributes determining consumer acceptance because it enables consumers to distinguish between products of acceptable and unacceptable quality (Syam et al., 2021).

The 14-h treatment also yielded the highest aroma score (8.40 ± 0.07 ; **Table 1**), suggesting better retention of volatile compounds, whereas prolonged drying likely increased aroma loss. Similarly, the 14-h treatment produced a color score (8.36) comparable to that of commercial nori, while extended drying promoted non-enzymatic browning and reduced consumer acceptance. Color is a critical quality attribute influencing consumer perception and acceptance of food products (Prabaningrum et al., 2022). High drying temperatures and extended drying periods may reduce lightness and promote chlorophyll degradation through the Maillard reaction, resulting in a less desirable green color in nori (Widyastuti et al., 2021).

Overall, the 14-h drying treatment produced the best sensory quality and most closely resembled commercial nori. This drying duration provided an appropriate balance between moisture removal and preservation of desirable sensory characteristics, whereas both shorter and longer drying periods adversely affected organoleptic quality. Drying duration influences moisture evaporation, thereby contributing to the development of the characteristic aroma of dried products (Amrizal et al., 2020).

Physical Properties

The tensile strength measurements of the nori samples were obtained as primary data through analysis performed at the Central Laboratory of Universitas Brawijaya. The results of the thickness and tensile strength measurements are presented in **Table 2**.

Table 2. Thickness and tensile strength of nori subjected to different drying time treatments.

Drying Treatment	Thickness (mm)	Tensile Strength (N)
13 h	0.25 ± 0.01^d	13.21 ± 0.09^c
14 h	0.23 ± 0.01^c	12.18 ± 0.05^b
15 h	0.18 ± 0.01^b	10.76 ± 0.05^a
Commercial nori	0.05 ± 0.00^a	16.22 ± 0.02^d
Pamungkas <i>et al.</i> , (2019)	0.05	11.40

Note: Values are presented as **mean $\pm$ standard deviation**. Different superscript letters within the same column indicate significant differences among treatments ($p < 0.05$).

Thickness Measurement

As shown in **Table 2**, drying time significantly affected ($p < 0.05$) nori thickness, which decreased from 0.25 ± 0.01 mm (13 h) to 0.23 ± 0.01 mm (14 h) and 0.18 ± 0.01 mm (15 h). In comparison, the commercial nori exhibited a thickness of 0.05 ± 0.00 mm, consistent with the value reported by Pamungkas et al., (2019). The reduction in thickness was attributed to moisture evaporation during drying, which caused shrinkage of the product matrix. As drying time increased, greater moisture loss resulted in thinner nori sheets. The 14-h drying treatment produced a thickness closer to that of the commercial product than the 13-h treatment while avoiding the excessive shrinkage observed after 15 h of drying. These findings suggest that a drying duration of 14 h provided an appropriate balance between moisture removal and preservation of the structural integrity of the product. The thickness of nori is also influenced by the mold dimensions, the volume of the slurry, and the total solids content of the mixture (Pamungkas et al., 2019).

Tensile Strength Measurement

Drying time significantly affected tensile strength ($p < 0.05$), which decreased from 13.21 ± 0.09 N (13 h) to 12.18 ± 0.05 N (14 h) and 10.76 ± 0.05 N (15 h) (**Table 2**). Although lower than commercial nori (16.22 ± 0.02 N), all values exceeded the reference reported by Pamungkas et al., (2019). The 14-h treatment best preserved the mechanical properties of the nori. The superior tensile strength of commercial nori is mainly attributed to the use of *Porphyra* spp. as the primary raw material (Riyanto et al., 2015). During gel formation, polymer chains undergo cross-linking to produce a rigid and cohesive three-dimensional network, thereby enhancing the mechanical strength of the nori sheets. Consequently, commercial nori prepared from *Porphyra* spp. exhibits higher tensile strength than nori produced from alternative seaweed species (Riyanto et al., 2015).

Color Measurement (L^* , a^* , and b^*)

The color parameters (L^* , a^* , and b^*) were obtained as primary data through analyses performed at the Central Laboratory of Universitas Brawijaya. The results of the color measurements, including the L^* (lightness), a^* (red–green coordinate), and b^* (yellow–blue coordinate) values, are presented in Table 3.

Table 3. Color parameters (L^* , a^* , and b^*) of nori subjected to different drying time treatments.

Drying Treatment	L^* (Lightness)	a^* (Red–Green)	b^* (Yellow–Blue)
13 h	37.80 ± 0.14^d	5.76 ± 0.09^b	12.78 ± 0.10^b
14 h	36.45 ± 0.10^c	6.41 ± 0.10^c	12.73 ± 0.15^b
15 h	33.60 ± 0.11^b	6.53 ± 0.05^c	13.67 ± 0.11^c
Commercial nori	20.68	-1.65	5.73

Note: Values are presented as **mean $\pm$ standard deviation**. Different superscript letters within the same column indicate significant differences among treatments ($p < 0.05$).

Drying time significantly affected the L , a , and b^* color parameters ($p < 0.05$) (Table 3). The L^* value decreased from 37.80 (13 h) to 33.60 (15 h), indicating progressive darkening, likely due to non-enzymatic browning during drying. The L^* coordinate represents lightness, ranging from 0 (black) to 100 (white) (Sinaga, 2019). The L^* value of approximately 40 for nori (Nurfiani et al., 2017). Prolonged drying promotes the Maillard reaction, resulting in darker green nori (Nurfiani et al., 2017). Heat accelerates non-enzymatic browning in carbohydrate-containing foods by facilitating reactions involving reducing sugars, ultimately producing brown-colored compounds (Nurfiani et al., 2017).

In contrast, the a^* value increased from 5.76 to 6.53, indicating a shift toward the red region of the color spectrum. This increase is associated with the formation of Maillard reaction pigments and the concentration of pigments caused by moisture loss during drying. The green color of the nori originated primarily from the chlorophyll present in *Moringa oleifera* leaves. The increase in a^* values with extended drying time suggests progressive chlorophyll degradation. (Pamungkas et al., 2019) reported an a^* value of -1.56 for nori, whereas (Sinaga, 2019) described the a^* coordinate as representing the green–red axis, with negative values indicating greener colors and positive values indicating redder colors. The a^* coordinate ranges from -128 to $+127$ (Utomo & Sinurat, 2022). The observed increase in a^* values is therefore consistent with chlorophyll degradation during thermal processing (Nazwa & Rahayu, 2020).

Similarly, the b^* value increased from 12.78 to 13.67, indicating greater yellow color intensity with increasing drying time. The b^* coordinate represents the blue–yellow axis and ranges from -128 to $+127$ (Utomo & Sinurat, 2022). (Pamungkas et al., 2019) reported a b^* value of 3.43 for nori. Negative b^* values indicate a bluish hue, whereas positive values indicate a yellowish hue (Sinaga, 2019). The increase in b^* values observed in this study suggests that prolonged drying enhanced the yellow coloration of the nori. Thermal processing promotes browning reactions that alter carotenoid pigments, resulting in a yellowish-brown appearance (Pramudya et al., 2022). Compared with the commercial product, all drying treatments produced higher L^* , a^* , and b^* values. Among the treatments, drying for 14 h resulted in the most balanced color characteristics, maintaining relatively high lightness while avoiding excessive increases in the red and yellow color coordinates.

Antioxidant Activity

The antioxidant activity data were obtained as primary data through analyses conducted at the Laboratory of Life Science (LSIH), Universitas Muhammadiyah Malang. The antioxidant activity of nori produced under the three different drying time treatments is presented in Table 4.

Table 4. Antioxidant activity of nori subjected to different drying time treatments.

Drying Treatment	Antioxidant Activity (IC ₅₀ , ppm)	Category	Molyneux Classification
13 h	122.38 ± 0.18 ^a	Moderate	< 50: Very strong
14 h	137.27 ± 0.15 ^b	Moderate	50–100: Strong
15 h	150.35 ± 0.10 ^c	Moderate	100–150: Moderate
Commercial nori	199.25 ± 0.02 ^d	Weak	150–200: Weak

Note: Values are presented as **mean ± standard deviation**. Different superscript letters within the same column indicate significant differences among treatments ($p < 0.05$).

Drying time significantly affected antioxidant activity ($p < 0.05$) (**Table 4**). IC₅₀ values increased from 122.38 ± 0.18 ppm (13 h) to 150.35 ± 0.10 ppm (15 h), while commercial nori exhibited an IC₅₀ of 199.25 ± 0.02 ppm. According to the Molyneux classification, the dried samples showed moderate antioxidant activity, whereas the commercial product showed weak activity. The decline in antioxidant activity with prolonged drying is attributed to thermal degradation of antioxidant compounds. Longer exposure to heat decreases the stability of bioactive compounds, resulting in reduced free radical scavenging capacity. These findings are consistent with those of (Sucianti et al., 2021), who reported that antioxidant bioactive compounds are heat-sensitive and that prolonged thermal drying significantly reduces antioxidant activity. Similarly, (Setyobudi et al., 2022) classified the antioxidant activity of nori as weak. Antioxidant compounds are susceptible to degradation when exposed to oxygen, light, elevated temperatures, and prolonged drying (Suryaningrum et al., 2006). Furthermore, the use of inappropriate extraction solvents may also reduce the measurable antioxidant activity of food products.

Variations in the antioxidant capacity of nori are influenced by the bioactive compounds present in the raw materials, particularly phenolic compounds, which are known to contribute substantially to antioxidant capacity. In addition to phenolics, other bioactive constituents naturally present in seaweed also contribute to the antioxidant properties of nori. Seaweeds contain numerous bioactive compounds exhibiting antioxidant activity (Zakaria et al., 2017).

The increase in IC₅₀ values observed with extended drying time indicates a decline in antioxidant activity resulting from prolonged thermal processing. Extended heating is likely to promote the degradation of bioactive compounds, including phenolic compounds and natural pigments, thereby reducing their free radical scavenging ability. Nevertheless, all experimental nori samples exhibited stronger antioxidant activity than the commercial nori. Among the treatments, the 14-h drying duration produced nori with moderate antioxidant activity while maintaining superior physical quality, indicating that this treatment provided the most favorable balance between functional properties and product quality.

The antioxidant activity of the nori was also influenced by the added ingredients, particularly the fresh *Moringa oleifera* leaves incorporated into the formulation. *M. oleifera* leaves exhibited an IC₅₀ value of 50.59 ppm, corresponding to very strong antioxidant activity (Riskianto et al., 2021). In contrast, sun-dried *Kappaphycus alvarezii* has been reported to possess an IC₅₀ value of 693.90 ppm, indicating weak antioxidant activity (Amelia & Tanod, 2016). Therefore, the incorporation of *M. oleifera* leaves likely contributed substantially to the enhanced antioxidant activity observed in the nori produced in the present study.

CONCLUSION

Drying time significantly affected ($p < 0.05$) the sensory, physical, and antioxidant properties of nori produced from *Kappaphycus alvarezii* supplemented with *Moringa oleifera* leaves. Among the tested treatments, drying for 14 h produced the best overall quality, characterized by the highest sensory acceptance, balanced physical properties, and moderate antioxidant activity superior to that of the commercial product. These findings indicate that a 14 h drying time is the optimum condition for producing high-quality nori and provides a practical processing reference for seaweed-processing industries and small- and medium-sized enterprises (SMEs) seeking to

develop value-added nori from locally available *K. alvarezii*. Future studies should evaluate the combined effects of drying temperature, drying technology, and *M. oleifera* concentration to further optimize product quality and support commercial-scale production.

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