pagepress

Italian Journal of Food Safety

Italian Journal of Food Safety 2026; 15:13812
doi:10.4081/ijfs.2026.13812

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Assessment of chemical, heavy metal, and microbiological contamination of Indonesian seaweed-based food products

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Abstract

Indonesia ranks as the second-largest global producer of seaweed. To maximize the use of these resources, innovative seaweed-based food products are being developed. This study evaluates the prevalence of chemical and microbiological contamination in Indonesian seaweed-based food products. Microbiological parameters assessed included total viable count, coliforms, *Escherichia coli*, *Staphylococcus aureus, Vibrio* species, *Salmonella* species, and yeast and mold. Chemical contamination was evaluated by measuring aflatoxin B1 and conducting a comprehensive assessment of heavy metals. Results indicated that 20% of samples contained aflatoxin B1 at concentrations ranging from 0.14 to 2.12 µg/kg. Heavy metal analysis showed contamination with lead in 50% of samples, arsenic in 35%, cadmium in 25%, and mercury in 5%. Only 25% of heavy-metal-contaminated samples exceeded the Indonesian National Standard limits. Microbial counts ranged from fewer than 10 to 105 CFU/g, coliforms from fewer than 3 to 830 MPN/g, and yeast and molds from fewer than 10 to 102 CFU/g. All samples had *E. coli* and *S. aureus* counts below 10 CFU/g and tested negative for *Salmonella* and *Vibrio* species. Most products were assessed as safe for consumption. The findings underscore the need for improved food-processing practices to enhance product quality, ensure higher safety standards, and increase overall market value.

Key words: aflatoxin, heavy metals, microbiological contamination, seaweed-based food products.

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Introduction

Indonesia ranks as the second-largest seaweed producer globally, following China. With a marine area of 5.8 million km², the country is a major contributor to Asia's seaweed production (Food and Agriculture Organization, 2018). Despite this, only 9% of the approximately 12 million hectares of suitable coastal areas are currently utilized for seaweed cultivation (Ni'mah *et al*., 2017; van der Heijden *et al.*, 2022). In 2021, total seaweed production reached 9 million tons. Most of this output consists of raw or dried seaweed, while the remainder serves as raw material for the food, pharmaceutical, and cosmetic industries (KKP, 2023).

According to the Ministry of Marine Affairs and Fisheries of the Republic of Indonesia, the country produces several seaweed species, including *Kappaphycus alvarezii*, *Euchema* spp., *Gracilaria* spp., and *Sargassum* spp. (KKP, 2023). These species are primarily processed into carrageenan, agar, and alginate products (KKP, 2023). Despite widespread production of these derivatives, demand for seaweed in the food sector continues to increase, driven by its recognition as a functional food (Peñalver *et al*., 2020; Ivanov *et al*., 2021). This trend is expected to expand utilization across a wide range of food products and stimulate innovation, leading to the introduction of various seaweed-based products, such as soft candies, snacks, and biscuits. Most of these products are produced by small-scale industries, which raises concerns about their quality and safety (van der Heijden *et al*., 2022). Recent studies highlight that establishing and maintaining consistent quality parameters for dried seaweed remains a significant challenge for the industry's future development (Setiowati *et al*., 2026). For instance, Setiowati *et al.* (2024) found that although many parameters for *Gracilaria* sp. in Central Java are met, several critical factors—including moisture content, impurities, lead (Pb) levels, and microbial contamination—often fail to meet specifications due to inconsistent implementation of good aquaculture practices. Contamination in dried seaweed poses a substantial barrier to industry growth and food safety, encompassing physical, chemical, and microbiological risks. These contaminants can arise at multiple stages of the supply chain, from cultivation and harvesting to post-harvest processing and storage. For example, conventional open-sun drying methods commonly used in Indonesia expose seaweed to dust, insects, and other environmental pollutants, compromising hygiene and overall product quality (Putri *et al*., 2018).

Common physical contaminants, such as sand and mud, result from traditional drying, in which seaweed is spread on the ground or beaches (Setiowati *et al*., 2024). Seaweed absorbs minerals from its environment, so heavy metal buildup is a concern. High Pb levels are a major risk and usually result from contaminated harvest waters. Studies in places like Saumlaki and Flores show cadmium (Cd) levels from 0.02 to 0.92 mg/kg (Notowidjojo *et al*., 2021). Some regions have low levels, while others show greater accumu-

lation due to local conditions. Tin (Sn) and mercury (Hg) are also tracked, but they usually remain below the detection limit in some Indonesian samples (Notowidjojo et al., 2021). Coliforms, mold, and yeast are common contaminants in seaweed (Setiowati *et al.*, 2024). Some samples show yeast and mold counts from 10 to 10^7 cfu/g (Notowidjojo *et al*., 2021). High moisture levels, poor hygiene, and poor water management increase microbial risks. Better drying and stricter hygiene are needed to meet global quality standards (Setiowati *et al*., 2026).

Strong regulations and advanced processing are essential for the safe production of seaweed-based foods (Stévant and Rebours, 2021; Cotas *et al*., 2024). Without clear national regulations or industry standards, there is a global gap in seaweed food safety that needs urgent attention (Ibrahim *et al*., 2025). Small and medium-sized businesses, in particular, struggle with unclear regulations, making it harder to invest in better practices and quality control.

A comprehensive evaluation of food safety requires detailed consideration of chemical and microbiological risks. A complete understanding of these two parameters is imperative to ensure quality assurance and consumer protection. Exposure to chemical contaminants, such as aflatoxin and heavy metals like arsenic (As), Pb, Hg, and Cd, can lead to serious health concerns, including cancer, particularly at elevated levels (Choudhury *et al*., 2022). According to the World Health Organization (2024), microbiological contamination, including pathogens such as *Escherichia coli*, *Salmonella spp.,* and *Vibrio spp.*, is responsible for many foodborne illnesses. Symptoms of this condition include fever, headache, vomiting, abdominal pain, and diarrhea. These contaminants can arise during manufacturing, and a high level of microbiological contamination may indicate substandard handling practices. Implementing proper hygiene measures and following good manufacturing practices have been proposed as effective measures to control and prevent such contamination (Tropea, 2022).

Contamination risks encountered during harvesting, processing, and packaging pose significant challenges to the safety of seaweed-based food products. This study systematically assesses the chemical and microbiological quality of seaweed-based processed products in Indonesia. The findings underscore the necessity for accessible product safety information for both consumers and producers and support recommendations to enhance product quality and safety.

Materials and Methods

Materials

The samples utilized in this study are processed local seaweed products of various types obtained from varied regions across Indonesia. A total of 20 products were collected. Agar powder products were collected from multiple cities in Indonesia, including Malang, Yogyakarta, and Jakarta Special Province on Java Island. In addition, the collection included biscuits, jelly candy, and seaweed stick snack products from Lombok, West Nusa Tenggara, Indonesia. Carrageenan and dried seaweed products were obtained from Surabaya, East Java, Indonesia. Seaweed powder seasoning and raw seaweed crackers were obtained from Makassar, South Sulawesi, Indonesia. Lastly, seaweed salt products and snacks were obtained from West Java, Indonesia. All chemicals and microbiological media were from Merck (Merck KGaA, Darmstadt, Germany), unless otherwise stated.

Methods

Aflatoxin B1 analysis

Aflatoxin B1 analysis was performed using a liquid chromatography-tandem mass spectrometry (LC-MS) system (LCMS-8060, Shimadzu, Kyoto, Japan). A mixed standard solution of mycotoxins was prepared in 2-mL amber vials. A 2-g sample of the test portion was weighed into a 50-mL Falcon tube, then ultrapure water was added and vortex-mixed. Thereafter, a measured volume of extraction solvent was added, and the mixture was shaken mechanically. Purification was then initiated using QuEChERS CEN salts, followed by a series of manual shaking and centrifugation steps. The resultant upper layer underwent dispersive solid-phase extraction clean-up techniques, and the purified extract was filtered into 2 mL amber vials before being introduced into the LC-MS/MS system. Chromatographic separation was achieved using a C18 column with a gradient elution system, where the mobile phase comprised 0.1% formic acid in ultrapure water (Phase A) and 0.1% formic acid in acetonitrile (Phase B). The flow rate was set at 0.4 mL/min using a gradient pump system.

Heavy metal analysis

The analysis of heavy metals (As, Hg, Pb, Cd, and Sn) was carried out using inductively coupled plasma mass spectrometry (ICP-MS 7900, Agilent Technologies, Palo Alto, USA). A calibration curve was prepared with at least six concentration points, and a precise amount of the sample between 0.5 and 1.5 g was weighed, or an appropriate volume of the liquid test portion was pipetted into a digestion vessel. A 10-mL solution of concentrated nitric acid (HNO_3) was added, and the mixture was left to stand. The vessel was then sealed and subjected to microwave digestion with a ramp program to 150°C for 10 minutes, followed by a hold at 150°C for an additional 15 minutes. After digestion, the sample solution was cooled and transferred into a 50-mL volumetric flask. The digestion vessel was then rinsed quantitatively with double-distilled water, and the rinsing solution was combined with the digested sample in the volumetric flask. Next, 0.4 mL of an internal standard mixture of germanium, indium, bismuth, and rhodium (10 mg/L) was added to the sample, followed by dilution to the calibration mark with ultrapure water. The analytes As and Hg were then mixed with the internal standard Ge, while the analytes Po and Po were mixed with the internal standard Bi. Similarly, the analytes Cd and Sn were mixed with the internal standard In. The solution was subsequently homogenized and filtered using a 0.29-µm syringe filter. Finally, the analyte concentrations in the prepared solution were measured using inductively coupled plasma mass spectrometry.

Microbiological analysis

Enumeration of total viable count, Escherichia coli, yeast, and molds

For sample preparation, 25 g of the sample was aseptically weighed and homogenized with 225 mL of 0.85% NaCl solution using a stomacher (Stomacher-80, Seward, West Sussex, United Kingdom) for 120 seconds at room temperature. Serial dilutions were prepared in the same diluent, and 0.1 mL or 1 mL aliquots of the appropriate dilutions were plated in duplicate using the pour plate or spread plate method on the following media: plate count agar for total viable count (TVC): the plates were incubated at 37°C for 48 hours; tryptone bile glucuronic agar (HiMedia Laboratories, Maharashtra, India) for *E. coli,* followed by incubation at 37°C for 48 hours; and potato dextrose agar for yeast and mold: the plates were incubated at 25°C for 72 hours. Following the incubation period, characteristic colonies for each microbial

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group were enumerated, and the results were expressed as colony-forming units per gram (CFU/g).

Enumeration of coliforms

Coliform enumeration was executed using the most probable number (MPN) method. A 1-mL aliquot of each appropriate dilution was inoculated into three tubes of lactose broth and incubated at 37°C for 24-48 hours (presumptive test). Positive tubes showing turbidity and gas production were further analyzed by transferring 1 loopful from each tube into 10 mL of brilliant green lactose bile broth (Oxoid, Basingstoke, United Kingdom) and incubating at 37°C for 48 hours to confirm the results.

Detection of Salmonella spp.

Salmonella spp. Detection was performed according to ISO Standard No. 6579-1:2017 (ISO, 2017a) by suspending 25 g of the sample in 225 mL of buffered peptone water (BPW) and incubating at 37°C for 24 hours (pre-enrichment). A 0.1 mL aliquot of the culture was then transferred to 10 mL of Rappaport-Vassiliadis selective enrichment broth and incubated at 41°C for 24 hours (selective enrichment). Following enrichment, the culture was streaked onto Xylose Lysine Deoxycholate agar and incubated at 37°C for 24 hours. Confirmation of colonies was performed using a set of biochemical tests, including Triple Sugar Iron (TSI) agar, urea agar, l-lysine decarboxylase broth, β-galactosidase, and indole tests. Serological confirmation was facilitated by agglutination with anti-O, anti-H, and anti-Vi sera.

Enumeration and detection of Staphylococcus aureus

Enumeration of *S. aureus* was conducted according to ISO Standard No 6888-1:2021A (ISO, 2021). A 25 g sample was aseptically homogenized in 225 mL of BPW and then serially diluted. A 0.1 mL aliquot was spread in duplicate onto Baird-Parker Agar and incubated at 37°C for 24 hours. Positive colonies appeared as black or gray, shiny, convex colonies surrounded by a clear or opaque halo that were inoculated into Brain Heart Infusion Broth and incubated at 35°C for 24 hours. Then, 0.1 mL of the culture was mixed with 0.3 mL of rabbit plasma and incubated at 35°C for 5 hours. A positive result was indicated by visible clot formation.

Detection of Vibrio spp.

The detection of *Vibrio* spp. was performed in accordance with ISO Standard No. 21872-1:2017 (ISO, 2017b). A 25 g sample was homogenized in 225 mL of alkaline saline peptone water and incubated at 37°C for 6-24 hours. For the isolation and identification of the enriched cultures, the samples were streaked onto Thiosulfate Citrate Bile Salts Sucrose agar and incubated at 37°C for 24 hours. The biochemical confirmation process included performing oxidase, Gram staining, motility, and decarboxylase tests.

Results and Discussion

Aflatoxin B1 contamination

Contamination risks during harvesting, processing, and packaging increasingly challenge the safety of seaweed-based food products. Fungal contamination, particularly in dried seaweed, is a significant concern due to the potential presence of mycotoxin-producing fungi, including Aspergillus and Penicillium species (Cotas *et al*., 2024). These fungi can proliferate under improper drying, storage, or handling conditions, especially in warm, humid climates such as those in Indonesia (Abdullah *et al*., 2024). Inadequate moisture reduction during drying or storage in high-humidity environments substantially increases the risk of fungal growth. Given these challenges (Soethoudt *et al*., 2022; Farghl *et al*., 2023), this study provides a comprehensive assessment of the quality of Indonesian seaweed-based food products. The findings underscore the importance of accessible product safety information for both consumers and producers and offer recommendations to enhance overall product quality and safety.

Aflatoxin B1 is a highly toxic mycotoxin with carcinogenic and hepatotoxic effects. Fungal contamination may occur in seaweed, especially in dried seaweed, if drying and storage conditions are inadequate, thereby increasing the risk of mycotoxin production (Li *et al*., 2018). Monitoring and quantifying aflatoxins, particularly aflatoxin B1, in seaweed products is critical for public health protection, as these toxins cannot be neutralized through conventional cooking methods (Julyasih and Purnawati, 2019). Although aflatoxin contamination is a widespread concern in various food products, including peanuts and corn, data on its prevalence in seaweed-based products remain limited in the literature.

As indicated in Table 1, many seaweed-based processed food products exhibited no detectable levels of aflatoxin B1. However, certain products, such as seaweed noodles and snacks, tested positive for traces of aflatoxin B1 contamination. Currently, no specific regulations limit mycotoxin contamination in processed seaweed products in Indonesia. However, Regulation No. 18 of 2018, promulgated by the Indonesian Food and Drug Authority (BPOM, 2018), stipulates a maximum permissible limit of 15 ppb (mcg/kg) for aflatoxin B1 contamination in processed foods. The analysis showed that all the tested seaweed products were within this permissible limit. Knowing that none of the tested samples exceeded regulatory limits for aflatoxin provides significant assurance of

Table 1. Aflatoxin B1 contamination in seaweed-based food products (mcg/kg).

No	Product/origin	Aflatoxin B1
1	Agar powder (Malang, East Java)	ND
2	Agar powder (Yogyakarta, Java)	ND
3	Agar powder (DKI Jakarta, Java)	ND
4	Seaweed biscuit with chocolate filling (Lombok)	ND
5	Seaweed biscuit with tiramisu filling (Lombok)	ND
6	Carageenan (Surabaya, East Java)	ND
7	Seaweed (dried) spinossum (Surabaya, East Java)	ND
8	Seaweed powder (Makasar, Sulawesi)	ND
9	Seaweed jelly candy (Lombok)	ND
10	Seaweed jelly fruit candy (Lombok)	ND
11	Seaweed instant noodle (Karawang, West Java)	0.3
12	Agar noodle strips (Karawang, West Jawa)	ND
13	Raw seaweed cracker (Makasar, Sulawesi)	ND
14	Seaweed salt (West Java)	ND
15	Snack seaweed chips (Bekasi, West Java)	ND
16	Snack seaweed chips (Pangandaran, West Java)	0.14
17	Snack seaweed crackers (Bekasi, West Java)	2.12
18	Snack seaweed pilus (Bekasi, West Java)	ND
19	Snack seaweed stick (Lombok)	ND
20	Snack seaweed tortila (Bekasi, West Java)	1.16

ND, not detected.

consumer safety, as chronic exposure to aflatoxin B1 has been linked to liver cancer, immunosuppression, and growth impairment (Nazareth *et al*., 2024). Aflatoxin B1 contamination is notably concerning because it is one of the most potent naturally occurring carcinogens, harming both human and animal health. Rushing and Selim (2019) reported that aflatoxin B1, a toxin produced by *Aspergillus* fungi, poses an important carcinogenic and highly toxic threat, thereby increasing the risk of cancer. The relatively low levels of aflatoxin B1 detected in Indonesian seaweed products could be attributed to the production and processing methods used. Certain drying techniques, such as sun-drying and controlled mechanical drying, have been reported to reduce fungal contamination and mycotoxin production by limiting moisture levels and inhibiting fungal growth (Semple *et al*., 1989). Additionally, differences in harvesting and post-harvest handling practices, as well as geographical and climatic conditions, may help minimize aflatoxin contamination in these products.

Mycotoxin contamination in micro- and macro algae products has been documented, demonstrating a broader concern for these secondary metabolites across diverse aquatic-derived foodstuffs (Li *et al*., 2018; Jakubczyk *et al*., 2024). This stresses the importance of strict quality-control measures in seaweed and microalgae production to ensure food safety and regulatory compliance.

Heavy metals contamination

Heavy metal contamination in food products represents a critical public health concern due to its potential toxicity and long-term health risks. As a marine-derived food source, seaweed can accumulate heavy metals from surrounding waters, necessitating routine monitoring to ensure consumer safety.

The results of heavy metal analysis are presented in Table 2, indicating that 35% of samples contained As and 50% contained Pb, while approximately 40% were free of heavy metal contamination. Consumption of heavy metals in food can result in serious health effects, including nervous system disorders, brain damage, paralysis, growth inhibition, kidney damage, DNA damage, brittle bones, and cancer (Jairoun *et al*., 2020; Prashant *et al*., 2025). Sources of contamination include environmental pollution in water and soil, which may increase during distribution (Begum *et al*., 2023). Additionally, metal equipment used in handling and processing can contribute to heavy metal contamination (Morgan, 1999). The fluctuating levels of heavy metal accumulation in seaweed are largely influenced by the specific cultivation or extraction site, underscoring the necessity for localised analyses rather than broad generalizations (Khandaker *et al*., 2021).

In this study, no significant correlation was found between the type of seaweed-based product or the geographical origin of the samples and contamination with any of the heavy metals analyzed ($p>0.05$). This lack of correlation may be attributed to multiple factors, including variations in environmental exposures that are not region-specific. Additionally, post-harvest handling and processing practices, such as washing, drying, and packaging, may have contributed to reduced contamination levels across sample types. The absence of correlation indicates that contamination is more likely to be affected by sporadic environmental pollution events rather than by a consistent regional trend. Additional investigation into the specific sources of contamination, including industrial discharge, agricultural runoff, and atmospheric deposition, is necessary to fully understand the mechanisms determining heavy metal accumulation in seaweed-based products.

According to the Indonesian National Standard (SNI) (BSN, 2015a) 2802:2015, the maximum permissible level of As contamination in agar powder is 3 mg/kg. The agar powder products in this study did not exceed this limit. However, for dried seaweed

Table 2. Heavy metal contamination in seaweed-based food products (mg/kg).

No	Product/origin	Arsenic	Cadmium	Mercury	Lead	Tin
1	Agar powder (Malang, East Java)	0.1	ND	ND	0.12	ND
2	Agar powder (Yogyakarta)	ND	ND	ND	0.13	ND
3	Agar powder (DKI Jakarta)	ND	ND	ND	0.12	ND
4	Seaweed biscuit with chocolate filling (Lombok)	ND	ND	ND	ND	ND
5	Seaweed biscuit with tiramisu filling (Lombok)	ND	ND	ND	ND	ND
6	Carrageenan (Surabaya, East Java)	ND	ND	ND	ND	ND
7	Seaweed (dried) spinossum (Surabaya, East Java)	ND	ND	ND	0.48	ND
8	Seaweed powder (Makasar, Sulawesi)	7.96	0.07	0.01	1.58	ND
9	Seaweed jelly candy (Lombok)	ND	ND	ND	ND	ND
10	Seaweed jelly fruit candy (Lombok)	ND	ND	ND	ND	ND
11	Seaweed instant noodle (Karawang, West Java)	ND	ND	ND	0.32	ND
12	Agar noodle strips (Karawang, West Jawa)	ND	ND	ND	0.53	ND
13	Raw seaweed cracker (Makasar, Sulawesi)	0.46	0.13	ND	0.14	ND
14	Seaweed salt (West Java)	5.21	ND	ND	nd	ND
15	Snack seaweed chips (Bekasi, West Java)	0.46	0.13	ND	0.14	ND
16	Snack seaweed chips (Pangandaran, West Java)	0.42	0.13	ND	nd	ND
17	Snack seaweed crackers (Bekasi, West Java)	0.14	0.02	ND	0.16	ND
18	Snack seaweed pilus (Bekasi, West Java)	ND	ND	ND	ND	ND
19	Snack seaweed stick (Lombok)	ND	ND	ND	ND	ND
20	Snack seaweed tortila (Bekasi, West Java)	0.1	0.07	ND	0.13	ND

ND, not detected.

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products, seaweed powder exceeded the 1.0 mg/kg As limit stipulated by SNI 2690:2015 (BSN, 2015b). Furthermore, salt products exceeded the 0.1 mg/kg As limit stipulated by SNI 3556:2016 (BSN, 2016a). Moreover, the analysis showed that certain seaweed-based snack products exceeded the 0.25 mg/kg As limit stipulated by SNI 2886:2015 (BSN, 2015c).

Furthermore, Cd contamination was detected in 25% of the samples, predominantly in snack products. However, the Cd levels in seaweed powder and snacks were within the safe limits of 0.1 mg/kg and 0.2 mg/kg, respectively, as stipulated by SNI 2690:2015 and SNI 2886:2015. While Hg contamination was observed in one out of twenty samples, it was within the permissible limit of 0.5 milligrams per kilogram for dried seaweed products, as stipulated by SNI 2690:2015. The study showed that half of the samples contained Pb. Agar powder and seaweed noodles were within the safe limits of 3 mg/kg and 2 mg/kg, respectively, as stipulated by SNI 2802:2015 and SNI 01-3551-2000 (BSN, 2000). However, certain dried seaweed products exceeded the 0.3 mg/kg Pb limit stipulated in SNI 2690:2015. Conversely, none of the snack products exceeded the 0.25 mg/kg Pb limit stipulated by SNI 2886:2015. Notably, all samples were found to be free from Sn contamination.

Microbiological contamination

Microbiological safety in seaweed-based food products is essential for consumer health and product quality. Contamination may occur during harvesting, processing, packaging, or storage, necessitating routine microbiological assessment (Barberi *et al*., 2019). Elevated microbial loads can indicate inadequate hygiene, suboptimal processing, or environmental contamination, presenting health risks. In this study, microbiological analyses were performed in accordance with SNI, ISO, and Food and Drug Administration guidelines, assuring reliable detection and quantification of microbial contaminants and providing important insights into product hygiene and safety. The microbiological contamination of seaweed-based food products is presented in Table 3. The findings indicated that total plate counts varied substantially across samples, with some exceeding established regulatory limits for microbial load in food products. Specifically, a substantial proportion of samples showed elevated aerobic plate counts, implying possible sanitation issues during production or storage.

The TVC parameter assessed the bacteria levels in seaweed-based processed products, yielding variable results. The significance of the TVC in food testing is emphasized by its capacity to reveal the extent of bacterial contamination. Assessing this parameter can serve as an indicator of product hygiene, consequently contributing to product safety assessment (Wei *et al*., 2023). The quantity of bacteria in food is categorized as high or low based on the food category stipulated by regulation. According to the TVC limits stipulated by the SNI 2802:2015 and the Indonesian Food and Drug Authority (BPOM, 2019) Regulation No. 13 of 2019, which specifies a limit of 10^3 colonies/g for agar products, most agar powder samples exceeded this limit. Conversely, biscuit products were safe, as the maximum TVC limit is 5×10^4 colonies/g, as stipulated by SNI 2973:2022 (BSN, 2022). The elevated TVC in agar powder may be due to inadequate drying, which can retain moisture and promote microbial growth.

In contrast, the lower TVC in biscuits is attributed to baking, which effectively reduces the microbial load by lowering water activity. These differences show the critical role of proper drying in agar powder production and the microbial inactivation achieved through heat treatment in baked products (Alp and Bulantekin, 2021). Carrageenan products were within the acceptable limit of 5×10^3 colonies/g, as specified by SNI 8391-1:2017 (BSN, 2017). According to BPOM Regulation No. 13 of 2019, the maximum

Table 3. Microbiological contamination in seaweed-based food products.

No	Products/origins	TVC (CFU/g)	Coliform (APM/g)	*E. coli* (CFU/g)	Yeast and molds (CFU/g)	*Salmonella* spp. (/25g)	*S. aureus* (CFU/g)	*Vibrio* spp. (/25 g)
1	Agar powder (Malang, East Java)	2.9×10^3	813	<10	<10	negative	<10	negative
2	Agar powder (Yogyakarta)	1.1×10^5	830	<10	3.10×102	negative	<10	negative
3	Agar powder (DKI Jakarta)	<10	<3	<10	<10	negative	<10	negative
4	Seaweed biscuit with chocolate filling (Lombok)	4.4×10^2	<3	<10	<10	negative	<10	negative
5	Seaweed biscuit with tiramisu filling (Lombok)	<10	<3	<10	<10	negative	<10	negative
6	Carrageenan (Surabaya, East Java)	4.10×10^2	<3	<10	<10	negative	<10	negative
7	Seaweed (dried) spinossum (Surabaya, East Java)	1.08×103	<3	<10	<10	negative	<10	negative
8	Seaweed powder (Makasar, Sulawesi)	1.36×10^5	5.1	<10	<10	negative	<10	negative
9	Seaweed jelly candy (Lombok)	2.60×10^2	<3	<10	<10	negative	<10	negative
10	Seaweed jelly fruit candy (Lombok)	3.60×10^2	<3	<10	<10	negative	<10	negative
11	Seaweed instant noodle (Karawang, West Java)	2.71×10^4	240	<10	<10	negative	<10	negative
12	Agar noodle strips (Karawang, West Java)	8.10×10^3	<3	<10	<10	negative	<10	negative
13	Raw seaweed cracker (Makasar, Sulawesi)	5.40×10^4	<3	< 10	<10	negative	<10	negative
14	Seaweed Salt (West Java)	2.70×10^2	<3	<10	<10	negative	<10	negative
15	Snack seaweed chips (Bekasi, West Java)	1.45×10^4	<3	< 10	< 10	negative	<10	negative
16	Snack seaweed chips (Pangandaran, West Java)	3.55×10^2	<3	< 10	< 10	negative	<10	negative
17	Snack seaweed crackers (Bekasi, West Java)	3.00×10^2	<3	< 10	1.00×102	negative	<10	negative
18	Snack seaweed pilus (Bekasi, West Java)	<10	<3	< 10	< 10	negative	<10	negative
19	Snack seaweed stick (Lombok)	<10	<3	< 10	< 10	negative	<10	negative
20	Snack seaweed tortila (Bekasi, West Java)	1.08×10^4	<3	< 10	< 10	negative	<10	negative

TVC, total viable count.

TVC for dried seaweed is 10^5 colonies/g; thus, the dried seaweed sample was safe. However, the seaweed powder sample exceeded this limit.

Those findings are consistent with broader observations that the traditional processed squid, for instance, frequently exceeds acceptable TVC limits set by various food safety authorities, showing a widespread challenge in maintaining microbial quality in certain processed seafood products (Subuntith *et al*., 2021). This frequently stems from insufficient post-processing hygiene, leading to recontamination, or from inadequate drying, which fails to suppress microbial proliferation (Zhang *et al*., 2025). These variables collectively compromise product shelf life and heighten public health risks. The microbial load, particularly high initial bacterial counts, significantly affects the shelf life and sensory quality of seaweed products, though it does not always directly indicate that a product is unsafe. However, even at low levels, the presence of specific pathogenic microorganisms or toxigenic bacteria can still pose major health threats (Løvdal *et al*., 2021). It is essential to note that while some studies suggest a 7-log threshold for acceptable contamination in vegetable products, this does not universally apply to seaweed products, especially fermented varieties, where high bacterial counts are vital to product safety and characteristics (Wirenfeldt, 2023).

The safety of seaweed jelly candies was assessed using a TVC limit of 5×10^4 colonies/g, as specified in SNI 3574.2-2008 (BSN, 2008). Furthermore, seaweed noodles were within the permissible limit of 1×10^6 colonies/g, as stipulated by SNI 01-3551-2000. Moreover, the SNI 8272-2016 (BSN, 2016b) standard, which pertains to raw fish, shrimp, and mollusc crackers, stipulates a TVC limit of 10^5 colonies/g, securing the safety of raw cracker products. Furthermore, seaweed-based seasoning salt had a TVC within the acceptable limit of 10^4 colonies/g, as stipulated by BPOM Regulation No. 13 of 2019. However, processed seaweed snacks, which have a maximum limit of 10^4 colonies/g, exceeded this limit. However, the remaining products generally exhibited low viable count numbers and were within the established safety limit.

At the same time, certain products also tested positive for coliform bacteria, suggesting fecal contamination (Lytou *et al.*, 2021). The presence of these indicator organisms underscores the need for strict hygienic practices throughout the supply chain and robust microbial testing protocols to reduce potential public health risks (Sinurat *et al*., 2023). The coliform contamination test is a key tool in assessing food safety, as it identifies potential hygiene deficiencies that may occur during various stages of food handling, production, processing, and storage (Ghosh *et al.*, 2020). Examining coliform contamination is imperative because it is strongly associated with foodborne disease outbreaks. This contamination can also occur when uncooked water is used during food processing (Naratama and Santoso, 2020). A study revealed that 80% of samples had coliform levels below 3 MPN/g, indicating their safety. However, certain products exhibited elevated coliform levels, reaching up to 800 MPN/g, which exceeds the permissible limit of 3 MPN/g stipulated by BPOM Regulation No. HK.00.06.1.52.4011 of 2009 (BPOM, 2009). Agar powder, seaweed powder, and seaweed noodles exceeded this limit.

Contamination by yeast and mold can occur when airborne contaminants encounter food surfaces. Yeast and mold are microorganisms capable of surviving within environments not conducive to bacterial growth. These organisms can endure various environmental stresses, including low pH, low water activity, and elevated salt or sugar concentrations. Notably, the presence of yeast and mold in food can constitute significant health risks, as they can lead to food deterioration and, in turn, produce mycotoxins, toxic substances capable of causing cancer (Mendonca *et al*., 2020). A recent study on yeast and mold testing revealed that 80% of the samples were within the acceptable limits (<10 colonies/g). However, two products exceeded the established limits. Specifically, one agar powder product exceeded the 3×10^2 colonies/g limit stipulated by SNI 2802:2015, while seaweed crackers exceeded the 10^2 colonies/g limit established by BPOM Regulation No. 13 of 2019. These elevated mold and yeast counts often signal inadequate sanitation during processing or improper storage conditions that favor fungal proliferation, impairing both product quality and consumer safety.

The Food and Drug Administration (2019) asserts that *E. coli*, a pathogenic bacterium, poses a health risk if ingested. The bacterium can cause gastrointestinal illness, ranging from mild symptoms to serious complications, and some types can even lead to life-threatening infections. Contamination by *E. coli* can occur through its presence in water or through inadequate hygienic practices that allow the bacteria to contaminate food products during processing. Notably, the study found no evidence of *E. coli* contamination, with a detection limit of 10 colonies per gram in the samples examined.

Concurrently, all samples were negative for *Salmonella* spp. and *Vibrio* spp., indicating no contamination by these pathogens. *Salmonella* spp. is a primary cause of life-threatening foodborne diseases due to its rapid growth potential (Lipi *et al*., 2023). *Vibrio* sp. has also been identified as a pathogenic bacterium that frequently causes gastroenteritis. Both *Salmonella* spp. and *Vibrio* spp. have been identified in fishery products. Consuming these bacteria can lead to health complications, especially when food is undercooked or raw.

The study's results showed that 30% of the samples exceeded the maximum TVC limit, 20% exceeded the coliform limit, and 10% exceeded the yeast and mold limit. Notably, no *E. coli, Salmonella* sp., or *Vibrio* sp. was detected in any of the samples, indicating good hygiene and sanitation practices.

Conclusions

The tests on seaweed-based processed products revealed that most samples were not contaminated with aflatoxin B1. However, a small percentage of the samples showed traces of the toxin, with levels well within the safety limits stipulated by the SNI. These data were corroborated by the Indonesian Food and Drug Authority, which confirmed that the levels of aflatoxin B1 in the samples were well below the permissible limits defined by guidelines. Chemical contamination was detected in 35% of the samples, with As and Pb being identified as the primary contaminants. Notably, the levels of these contaminants were well within the safety limits stipulated by the SNI. No pathogenic bacteria, including *E. coli, S. aureus*, *Salmonella* sp., and *Vibrio* sp., were detected. However, some samples exceeded safety standards for TVC, particularly in agar powder and specific snacks, and exhibited elevated coliform levels. Although most products were deemed safe, the findings indicate a need to improve food-processing practices to enhance quality, safety, and market value. The study highlights the importance of refining quality standards and regulations, particularly for seaweed-based products, where more specific guidelines are urgently required. Producers should prioritize implementing good aquaculture practices and good manufacturing practices. Regular, mandatory staff training can help small- and medium-

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scale processors improve operational standards and reduce contamination risks. Establishing clear, product-specific safety and quality standards tailored to various seaweed-based foods is essential. Collaboration among industry groups, academic institutions, and government agencies can facilitate the dissemination of technical guidelines and best practices. Expanding access to laboratory analysis services for small producers and providing incentives for compliance can further promote the consistent production of safe, high-quality seaweed products.

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Received: 11 March 2025; Accepted: 23 March 2026; Early view: 23April 2026.

Contributions: Dian Anggraini Suroto: design, data analysis and interpretation, manuscript original drafting, editing. Restu Nurkholifah, Aiman Arkan, Muhammad Wildan Ashidiqie: samples acquisition and processing, contribution to manuscript writing and editing, Rachma Wikandari: manuscript writing and editing. All authors read and approved the final version of the manuscript and agreed to be responsible for all aspects of the work.

Conflict of interest: the authors declare that they have no competing interests, and all authors confirm accuracy.

Ethics approval and consent to participate: not applicable.

Availability of data and materials: all data generated or analyzed during this study are included in this published article.

Funding: National Research and Innovation Agency (BRIN) Indonesia for the funding provided for this research activity by the Decree of the Deputy for Research and Innovation Facilitation, National Research and Innovation Agency, Number RIIM: 34/IV/KS/06/2022.

Declaration of generative artificial intelligence and artificial intelligence-assisted technologies in the writing process: during the preparation of this manuscript, the authors used Grammarly to improve the grammar and language clarity. After using the service, the authors reviewed and edited the content as needed and take full responsibility for the content of the manuscript.

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