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# Improving the Quality of Dried Seaweed (*Gracilaria sp.*) Through the Implementation of Good Aquaculture Practices (GAP) in Brebes, Central Java

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**ABSTRACT**

This study aims to identify the quality of dry seaweed *Gracilaria sp.* cultivated in Brebes, West Java, Indonesia, and determine strategies to improve its quality through applying good aquaculture practices (GAP). The research methods used include field surveys, data collection, laboratory analysis, and application of good cultivation practices. The results showed that most of the required parameters met the specifications, except for moisture content, impurities, heavy metal Pb, microbial contamination (TPN), and mold/yeast contamination. Parameters that do not meet this requirement are related to aspects of GAP implementation that still need to be appropriate and need some improvement, especially in determining production locations, water management, product recording, and storage. Applying GAP also helps reduce negative impacts on the aquatic environment and increases the sustainability of seaweed farming. This research provides recommendations for seaweed farmers in Brebes Regency to implement GAP in cultivating *Gracilaria sp.* seaweed. This is expected to increase the quality of seaweed production, increase farmers' income, and maintain the sustainability of seaweed cultivation. Further research can be conducted to deepen the understanding of applying GAP in seaweed farming and its long-term effects on the environment and the sustainability of seaweed farming.

## 1. INTRODUCTION

Seaweed is an important commodity that is a source of livelihood for coastal communities in Indonesia and has been overgrown since 2000 [1-5]. Indonesia is one of the largest seaweed producers in the world, contributing more than 50% of total world seaweed production [6]. Seaweed production comes exclusively from community-based agricultural activities, provides a significant source of household income [1]. This industry has demonstrated positive economic and social impacts, contributing to increased prosperity and life satisfaction in coastal villages, as demonstrated by the very beneficial socio-economic effects of seaweed cultivation [1]. Seaweed cultivation also provides a crucial option for livelihood diversification during periods of extreme economic disruption, thereby serving as a mechanism to enhance the resilience of coastal communities [5]. This industry not only generates revenue through exports but also creates employment opportunities, particularly for small-scale farmers. Moreover, the global demand for seaweed products in various sectors, including food, pharmaceuticals, cosmetics, and agriculture, continues to grow, presenting profitable market opportunities for both Indonesia and other seaweed-producing countries worldwide [7, 8]. However, this industry is vulnerable to price fluctuations and production cycles, making seaweed farmers vulnerable to market fluctuations [5, 9]. The economic value obtained from seaweed production in Indonesia is also low, most of the production is exported as raw materials, thus providing limited economic benefits for farmers [9].

Although many seaweed species are cultivated commercially, only seven species account for more than 95% of the world's aquatic plant value. Four are found and produced in China, Korea, and Japan. In contrast, the other three species, namely *Gracilaria sp.*, *Eucheuma sp.*, and *Kappaphycus sp.*, are found and cultivated in Indonesia, which produces 66% of global seaweed [1, 10]. Seaweed production in Indonesia in 2022 will increase from 2021 with a value of 10.08 million tons [11] and is in second place as a producer of *Euchema cottoni* seaweed under China with production reaching 9.1 million tons [12].

Processed seaweed products are generally used by the food and non-food industries [13]. Seaweed handling is an important factor in determining the quality of seaweed [14-

16]. Seaweed can be marketed fresh but is usually dried at 50-60°C [17]. After drying, they are packaged and consumed through a cooking process or as ready-to-eat food without further processing [18, 19]. The trend of consuming dried seaweed as ready-to-eat food or raw materials in more complex formulations has given rise to a new discourse on public health. Potential food safety hazards occur at every stage of handling (Figure 1). In raw materials, foreign matter is the main potential that causes quality deterioration due to mishandling [20]. In addition, there is also the potential for contamination of pathogenic bacteria in seaweed, which can contaminate raw materials. These contaminants are formed during the cultivation and handling processes, and there is a clear relationship between the macroalgae and the bacteria that contaminate the surface of the seaweed because the seaweed provides temporary nutrition for the bacteria [18, 21]. Previous studies reported that microorganisms, namely *Listeria monocytogenes* and *Bacillus cereus*, were detected in seaweed-based foods. Although the study's results indicate *Bacillus cereus's* inability to reproduce, it is still necessary to explain the possible risks for consumers [17].

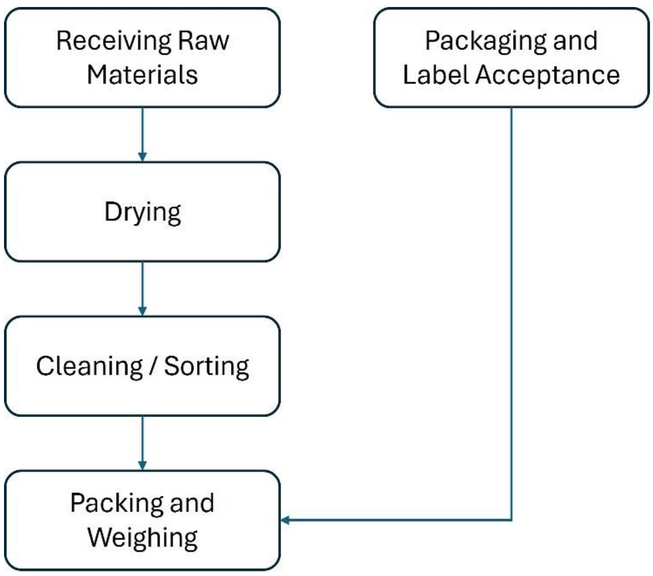


**Figure 1.** Seaweed handling process [22]

Apart from microbiological contaminants, heavy metal contamination is another risk that requires attention. Countries and organizations worldwide have introduced various policies and measures to minimize the damage caused by metal pollution in the marine environment [23]. Reference reported that the concentration of heavy metals in seaweed, *Caulerpa spp*. cultivated in ponds and consumed as food [24]. *Caulerpa spp*., being a source of additional nutrition can also accumulate heavy metals, which are potentially harmful to health. The heavy metals detected were arsenic (As) and lead (Pb) at concentrations close to national food safety limits. In addition, in the species of seaweed *Sargassum duplicatum* and *Padina tetrastromatica*, higher levels of cadmium (Cd) and lead (Pb) were identified for samples obtained from oil extraction sites compared to samples obtained from non-oil locations on Madura Island [25]. The content of heavy metal Pb also affects the chlorophyll and protein content of *Padina australis* seaweed. The correlation between the heavy metal content of Pb and protein shows a negative correlation, namely, the higher the heavy metal content of Pb in *Padina australis*, the lower the protein content [26].

The potential for contamination and hazards must be minimized during the seaweed handling process. The drying technique is one of the techniques commonly used in preserving seaweed [27, 28], the drying process is also a process that determines the quality of the dried seaweed produced. This process is an important stage because there is a potential danger of decay resulting from an uneven level of dryness leading to a decrease in the quality of dried seaweed. Potential hazards can be reduced by drying seaweed on racks or hanging and drying it according to specifications [28]. During drying, periodic reversals are carried out so the seaweed dries evenly.

Brebes Regency is one of Indonesia's major seaweed production centers, especially *Gracilaria sp.* [29]. This area is used for seaweed cultivation with shallow pond conditions with a muddy black substrate [30]. Overall, the condition of the waters of Brebes Regency was lightly polluted. Only one measurement point indicated a heavily polluted condition with nutrient conditions (nitrates and phosphates) and overall fat and oil content exceeding the quality standard thresholds for marine water quality. At the same time, the values of ammonia and total suspended solid (TSS) were still low within the quality standard value limits [31]. Nonetheless, the water quality is in the range that is feasible for seaweed cultivation activities [32]. Apart from the water quality factor [33], seaweed producers' knowledge and managerial aspects affect the production quality and quantity [34].

To improve the quality of dried seaweed, previous research proposed different techniques for drying, including tarpaulin, bamboo shelves, solar dryers, table-type sun drying, natural drying, cabinet drying, freeze-drying, vacuum drying, solar drying, and convective drying [35-40]. Research has assessed the efficiency of various drying techniques in decreasing moisture content, removing impurities, and enhancing the brightness of dried seaweed [35-37, 39, 41]. To evaluate the effects of drying methods, the quality attributes of dried seaweed, including moisture content, carrageenan content, gel strength, color, and presence of impurities, have been scrutinized [35-39, 41]. Post-harvest methods, such as saltwater and freshwater draining, have been demonstrated to influence the sensory qualities of dried seaweed and derived products such as syrup and pudding [41].

The Ministry of Maritime Affairs and Fisheries has established Guidelines for a Guidance System for Good Fish Raising Methods/Good Fish Cultivation Practices (CBIB) based on the Directorate General of Aquaculture Regulation Number 87/2022. These guidelines are also known as sustainable or good aquaculture practices (GAP) Indonesian version. These guidelines can be used as a reference in producing quality seaweed. CBIB includes applying seaweed cultivation methods and harvesting in a controlled environment to provide food security for farmers by paying attention to sanitation, feed, fish medicine, chemicals, and biology [42]. In comparison to previous methodologies and findings, the current study offers a comprehensive approach by integrating both quality assessment and adherence to GAP guidelines in seaweed cultivation. This study aimed to determine strategies for improving the quality of dried seaweed by applying CBIB or GAP in seaweed cultivation. By examining the correlation between quality parameters and GAP implementation, the research provides insights into how adherence to standardized practices can enhance the overall quality of seaweed production.

## 2. MATERIAL AND METHODS

### 2.1 Area of study

This study consisted of three stages: (1) Analyzing the quality of the dried *Gracilaria sp.* seaweed produced. (2) Analyzing the suitability of seaweed cultivation with the guidelines for good seaweed cultivation GAP. (3) Establishes a quality improvement strategy by compare the test results with the implementation of the GAP. The research used case studies on seaweed cultivators in Brebes Regency, Central Java Province (Figure 2).

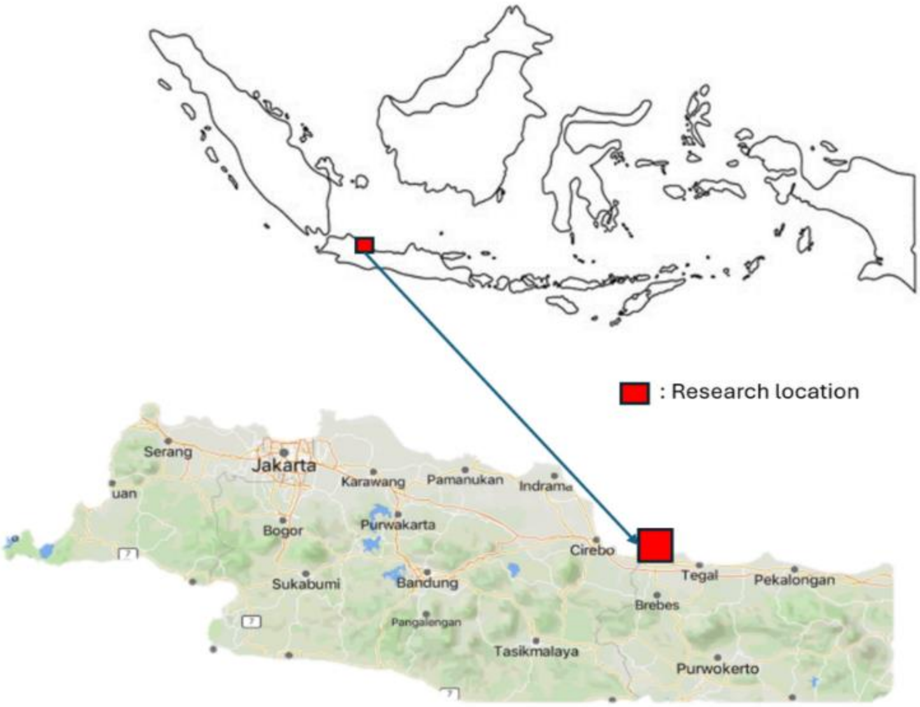


**Figure 2.** Research area

### 2.2 Sample testing

Seaweed samples were obtained from 20 dried seaweed cultivators of the *Gracilaria sp.* in Brebes Regency. The samples. Dried seaweed from cultivators was packed in such a way as to prevent deterioration and kept for further use. The quality parameters of the dried seaweed (*Gracilaria sp.*) determined based on SNI 2690:2018, among others are moisture content (%), impurities (%), Clean Anhydrous Weed (CAW) (%); heavy metals (Hg, Pb, Cd, As) [22]. Apart from that, testing was also carried out for aflatoxin B1 contamination and microbiological contamination (coliform, *Escherichia coli, Salmonella sp., Vibrio sp., Staphylococcus aureus,* and also yeast and mold).

**Moisture content (%)**

Testing of moisture content refers to the SNI 01-2891-1992 method. The sample weighed 1-3 g in a weighing bottle whose weight is known. Then dry the sample in an oven at 105°C for 3 hours and cool it in a desiccator. Weigh and repeat until a constant weight was achieved.

**Impurities (%)**

Testing of impurities is referred to the SNI 8169:2015 method. A sample of 250 g of seaweed was weighed. Seaweed was separated from all kinds of dirt (other seaweed, plastic, sand, and other foreign objects). The collected impurities were then weighed.

**Clean anhydrous weed (%)**

Clean anhydrous weed (CAW) is the net and gross weight ratio measured when washing seaweed before it is extracted to produce agar. The CAW analysis method was performed based on the SNI 8168:2015 method. A 60 g seaweed sample was soaked in 5 liters of clean water, then filtered and dried at 60°C for 30 minutes, then flattened and continued for 20 - 22 hours until the weight was constant.

**Heavy metal (mg/kg)**

The sample was put into the vessel and was added with concentrated $HNO_3$. The solution was left for 15 minutes. Afterward, the destruction was performed using a microwave digester. The sample was cooled, put into a volumetric flask, added to the internal standard mix, and added aquabidest up to the mark. The mixture was homogenized and filtered using a 0.20 µm syringe filter. The filter results were measured for intensity using the ICP-MS system [43].

**Aflatoxin B1 analysis**

This test was carried out using LC-MS/MS. The analysis was started by preparing a standard series of mixed mycotoxins in a 2 mL amber vial. Then 2 g of homogeneous test pore was added into a 50 mL falcon tube. Add aquabidest and vortexes. Add the solvent measuredly and extract it with a mechanical shaker. Add QuEChERS CEN salt and shake manually. Then, the solution was centrifuged, and a cleanup process was carried out using 1,2-Distearoyl-sn-glycero-3-phosphoethanolamine (dSPE). Filter the cleanup results into a 2 mL amber vial and inject it into the LC-MS/MS system [44].

**Coliforms analysis (CFU/g)**

This test referred to the SNI ISO 4832:2012 method [45]. This test was carried out by inoculating samples diluted to a

10-3 dilution of 1 mL of each dilution, then inoculated in 15 mL of crystal violet red bile lactose (VRBL) medium aseptically. Then incubated at 30°C or 37°C for 24±2 hours. If an atypical colony is found, proceed with a confirmation test. The confirmation test was carried out by inoculating atypical colonies into Brilliant Green Lactose broth tubes and incubating at 30°C or 37°C for 24±2 hours.

***Escherichia coli* analysis (MPN/g)**

This test was based on the SNI ISO 7251:2012 method [46]. 1 mL of the initial suspension was added to 9 mL of single-strength lauryl sulfate broth. Incubation was performed in an incubator at 37°C for 24±2 hours. If there was no gas formation, incubation was resumed for up to 48 ± 2 hours. If there was gas formation, the sample was inoculated into the *Escherichia coli* (EC) broth tube and incubated in an incubator at 44°C for 24±2 hours. If no gas was seen in the EC broth, the total incubation time was extended to 48±2 hours. The tube showing the presence of gas was then inoculated into the peptone water tube, which had been heated to 44°C and incubated for 24±2 hours at 44°C. Afterward, add 0.5 mL of indole reagent to the peptone water tube. Shake thoroughly after 1 minute. If a red color appears in the alcohol phase, it indicates the presence of indole. The calculation was performed using the MPN table.

***Salmonella sp.* analysis (CFU/25 g)**

This test referred to the ISO 6579-1:2017/AMD 1:2020 method [47]. This test was carried out in four stages. The first stage was the enrichment stage, which was carried out by taking 0.1 mL of sample into 10 mL of Rappaport-Vassiliadis soya peptone (RVS) broth and 1 mL of sample into 10 mL of Muller-Kauffmann tetrathionate novobiocin (MKTTn). The RVS broth solution was incubated at 41.5°C and the MKTTn solution was incubated at 34-38°C. Both solutions were incubated for 24±3 hours. The second stage was the selective stage. This stage was carried out by inoculating the enrichment sample onto Xylos-Lysine-Desoxycholat (XLD Agar) media using the streak plate method, which was then incubated at 34-38°C for 24±3 hours. The third stage was the biochemical stage. At this stage, the samples that had been incubated were then observed for typical colonies that appeared. Positive colonies from the three media were then transferred to the oblique and upright Triple Sugar Agar (TSIA), Urea Agar, and L-Lysine Decarboxylase (LDB) agar, β-galactosidase test, and indole test, which were then incubated at 34-38°C for 24 hours. The fourth stage was the observation stage. After incubation, the samples were then observed.

***Vibrio sp.* analysis (CFU/25 g)**

This test referred to the SNI ISO 21872-1:2017 method [48]. It was carried out in three test stages: the primary selective enrichment test, the second selective enrichment test, and isolation. In the primary selective enrichment test, the diluted sample was incubated at 37°C±1°C for 6±1 hour. Then, a second selective enrichment test was carried out by adding 1 mL of the culture obtained from primary selective enrichment into a tube containing 10 mL of alkaline saline peptone water (ASPW) and incubated at 41.5±1°C and 37°C±1°C for 18±1 hour, followed by the isolation stage. Each dilution was taken and inoculated on Thiosulfate Citrate Bile Salts Sucrose (TCBS) agar and Triphenyltetrazolium Chloride Soya Tryptone (TSAT) agar and incubated at 37°C±1°C for 24±3 hours.

***Staphylococcus aureus* analysis (CFU/g)**

This test refers to the ISO 6888-1:2021 method [49]. This test consists of a prediction test and a coagulase test. The prediction test was carried out by diluting the sample to a $10^{-3}$, taking 0.1 mL from each dilution, and inoculating it on Baird Parker agar using the spread plate method, then incubating for 24±2 hours at 35°C or 37°C. After the presumptive test, the plates containing typical colonies were transferred to a sterile Brain Heart Infusion solution with each tube containing 2 mL using eyelet loops and incubated for 24±2 hours at 35°C or 37°C.

**Total plate number analysis (CFU/g)**

This test referred to the SNI ISO 4833-1:2015 method [50]. Samples were diluted to 10-3 dilutions, 1 mL was taken from each dilution and then aseptically inoculated in the cup. Pour 12-15 mL of sterile PCA media (44°C-47°C). The cup was shaken so that the sample was evenly distributed and allowed to stand so that it thickened. Then, samples were incubated at 30°C±1°C for 72±3 hours. Colony counts were selected from petri dishes with 10-300 colonies in each dilution dish.

**Yeast mold analysis**

This test referred to the SNI ISO 21527-2:2012 method [51]. The sample was diluted to 10-3, 0.1 mL of the initial suspension, or the result was then transferred to DG18 media using the pour cup method. Samples were incubated at 25±1°C for 5-7 days.

## 2.3 GAP suitability analysis

In the GAP suitability analysis, researchers used a customized questionnaire tool from the Regulation of the Director General of Aquaculture of the Ministry of Maritime Affairs and Fisheries Number 87/2022 concerning Guidelines for the Guidance System for Good Fish Raising Methods/Good Fish Cultivation Methods. This was done by assessing the level of implementation of the basic feasibility of the GAP aspect at the research location using gap analysis. The gap analysis tool was used to identify the conformity gap between the GAP quality management system and the existing quality management system within the company. GAP analysis was carried out to assess the gap between business conditions and GAP parameters using the scoring system presented at Table 1. The percentage score range was then interpreted using Table 2. The score percentage and the sum of the weights were calculated using the following equation:

$$\%\,application = \frac{\Sigma\ score\ for\ each\ parameter}{\Sigma\ max\ score} \quad (1)$$

**Table 1.** Scoring for gap analysis

| Score | Description |
|---|---|
| 0 | If the manufacturer does not know the requirements |
| 1 | If the manufacturer knows about the requirements but does not carry out the activity |
| 2 | If the manufacturer knows about the requirements but performs activities only occasionally |
| 3 | If the manufacturer understands the requirements but does not always do it |
| 4 | If the producer understands and carries out activities but is not perfect |
| 5 | If the manufacturer understands and performs the activity perfectly |

Source: [52, 53]

**Table 2.** Range of percentages of GAP implementation fulfillment from the sum of the weights

| Score | Description |
|---|---|
| 75% - 100% | The company's quality management system program meets GAP requirements |
| 50% - 74% | The company's quality management system program still needs to be improved to meet GAP requirements |
| 1% - 49% | The company's quality management system program needs improvement because it is very different from the GAP requirements |

Source: [52, 53]

After obtaining the quality and gap analysis results, the two data were compared to obtain the relationship and impact of GMP implementation on the quality of the seaweed produced. Developing a quality improvement strategy was carried out by juxtaposing the parameters that cannot be met on the aspects of SNI and GMP.

### 2.4 Statistical analysis tools

Seaweed test data was analyzed using descriptive statistical tools, quantitative analysis with an exploratory approach. The descriptive exploratory approach is a research method that aims to collect initial information that will help determine the problem, formulate hypotheses, and analyze the problem [54]. This stage has the output of parameters in SNI that can be met by the sample and vice versa. Further analysis is carried out to determine the causes of nonconformities, possible anomalies and is linked to GAP analysis. Meanwhile, in the GAP analysis, the statistical tool used is the level of suitability based on the results of the scoring matrix and weighting using simple additive weighting (SAW). The SAW method is based on the concept of a weighted average where an evaluation score is calculated for each alternative parameter [55]. At this stage the analysis is carried out using equation 1 with scoring and type weighting (based on Tables 1 and 2) for each GAP parameter.

## 3. RESULT

### 3.1 Dried seaweed quality

The quality of dried seaweed needs special attention to obtain high-quality seaweed derivative products [56]. The seaweed processing business begins with seaweed cultivation by farmers followed by drying to obtain dried seaweed. The dried seaweed was then collected by collectors, from collectors to wholesalers, and exporters. Therefore, the quality of the seaweed produced is determined by handling and processing at the farmer level [14-16]. The quality of dried seaweed produced by farmers is important in the macro seaweed industry. Factors affecting dried seaweed production quality include cultivation land, supporting materials and facilities, seeds, and cultivator human resources [57].

**Table 3.** Test results for dried seaweed

| No. | Parameter | Unit | Method | Requirements | Test Results |
|---|---|---|---|---|---|
| 1 | Coliform | CFU/g | SNI ISO 4832:2012 | - | $1.0 \times 10^1$ |
| 2 | *Escherichia coli* | MPN/g | SNI ISO 7251:2012 | Max. $7.0 \times 10^2$ | 0.36 |
| 3 | *Salmonella sp.* | CFU/25 g | ISO 6579-1:2017/Amd 1:2020 | Negative | Negative |
| 4 | *Vibrio sp.* | CFU/25 g | SNI ISO 21871-1:2017 | - | Negative |
| 5 | *Staphylococcus aureus* | CFU/g | ISO 6888-1:1999/Amd 2:2018 | Max. $10^3$ CFU/g | <10 |
| 6 | Mercury (Hg) | mg/kg | 18-13-14/MU/SMM-SIG (ICP MS) | Max. 0.5 | 0.03 |
| 7 | Lead (Pb) | mg/kg | 18-13-14/MU/SMM-SIG (ICP MS) | Max. 0.3 | 2.67 |
| 9 | Inorganic Arsenic | mg/kg | 18-4-33/MU/SMM-SIG (AAS HVG) | Max. 1.0 | 0.60 |
| 10 | Cadmium (Cd) | mg/kg | 18-13-14/MU/SMM-SIG (ICP MS) | Max. 0.1 | 0.04 |
| 11 | Tin (Sn) | mg/kg | 18-13-14/MU/SMM-SIG (ICP MS) | - | Not detected |
| 12 | Aflatoxin B1 | mcg/kg | 18-12-17/MU/SMM-SIG (LC-MSMS) | - | Not detected |
| 13 | Total Plate Number | CFU/g | SNI ISO 4883-1:2015 | Max. $3.57 \times 10^3$ | $3.75 \times 10^5$ |
| 14 | Yeast Mold | CFU/g | SNI ISO 21527-2:2012 | Max. $2.33 \times 10^2$ | $1.65 \times 10^6$ |
| 15 | Moisture Content | % | SNI 01-2891-1992 point 5.1 | Max. 16 | 16.53 |
| 16 | CAW | % | SNI 2690:2018 | Min. 40 | 43.30 |
| 17 | Impurities | % | SNI 2690:2018 | Max. 3 | 4.30 |

The analysis results of the dried seaweed samples are presented in Table 3. Moisture content, lead (Pb) content, and microbial contamination (total plate count and mold/yeast) in the samples showed values above the specified quality requirements. This result might cause a decrease in the quality of dried seaweed. Moisture content, which is a crucial parameter [58], can influence the shelf life [59-62] and accelerate the growth of microorganisms [62, 63]. The latter was characterized by the value of the total plate number and mold/yeast of the sample which exceeded the required standard. High moisture content in dried seaweed products is generally caused by mishandling and drying techniques that have yet to be maximized [64]. In general, seaweed farmers in Brebes use conventional drying methods (sun drying). According to Mayol et al. [39], this direct drying technique can eliminate the moisture content in seaweed by up to 40%. However, this technique has a high risk of contamination of dirt from the surrounding environment and re-absorption of water by the seaweed. Several drying methods have been developed for seaweed, such as oven drying, vacuum drying, and low temperature drying (freeze drying) [64]. Based on Table 3, the CAW quality of *Gracilaria sp.* obtained still meets the SNI standards, namely 43.30%. However, the impurities content exceeds the SNI's parameters [22]. The causes of high impurities could be due to drying techniques that involved drying in open areas leading to contaminations from the surrounding environment during drying, as well as during handling before drying (mixing moss, coral, and sand during harvest) [56].

The test results also show that the concentration of Pb was above the predetermined standard. The presence of the heavy metal Pb in seaweed can come from the environment, especially during seaweed cultivation to harvesting. According to Filippini et al. [65], poor environmental conditions will potentially cause contamination of seaweed products. In general, cultivation locations not far from or along industrial waste disposal sites have the potential to cause contamination. In addition, the activities of residents around the cultivation site also determine the potential heavy metal contamination [66]. Seaweed is one of the natural bioindicators that accumulate contaminants from the environment, so the heavy metal content in seaweed reflects the environmental conditions in the waters and air pollution where it is grown [67, 68]. Makro or mikro alga memiliki kemampuan dalam phytoremediation pada media tumbuhnya [69]. In addition, *Gracilaria* seaweed has remediation properties known as hyperaccumulator plants [70]. The nature of *Gracilaria*, which has a high absorption capacity (bio-absorbent) on metals, especially Pb metal, causes high levels of Pb metal in *Gracilaria* [71]. So, in this case, it is necessary to identify the environmental conditions of seaweed cultivation in Brebes. Identification was then carried out on several potential causes of the high content of Pb metal in the produced seaweed. It was done to reduce and minimize the content of Pb in seaweed. Heavy metals are toxic at a certain amount accumulated in the body, even leading to cause cancer [72].

### 3.2 Analysis of the application of good aquaculture practices (GAP)

The GAP analysis tool was used to identify gaps in the GAP quality management system and existing quality management systems in seaweed farming companies [52]. If gaps within the company are known, then action can be taken to improve the quality management system within the company. Using this approach, one can ensure compliance with the GAP and increase the overall effectiveness of the quality management system (QMS) that exists within the company. GAP analysis assumes that an organization or company already has a QMS function and will improve the QMS function using the GAP reference.

The dry seaweed production process is carried out starting from the seaweed being deposited by farmers in a semi-dried state, the drying process, pressing, and packaging. Seaweed that has been harvested takes at least one full day (sunny day) to get the desired moisture content. In cloudy weather conditions, seaweed takes longer to dry. The moisture content that the company requires is usually between 16% for *Gracilaria sp.*, according to SNI 2690:2018.

GAP is by the Regulation of the Director General of Aquaculture of the Ministry of Maritime Affairs and Fisheries Number 87/2022, which is a reference for seaweed cultivators, food processing industry supervisors, and supervisors of processed food quality and safety. One of the goals of implementing GAP is to guarantee the quality and safety of fishery products [73]. Applying GAP is useful for improving and enhancing product quality and maintaining food safety [74]. The GAP design consists of 21 aspects, specifically for seaweed products, and 15 aspects, as presented in Table 4.

Based on Table 4, the total score of the fulfillment of the GAP aspect was 49. Compared to the maximum score of 75, the percentage of the fulfillment level of GAP implementation was 65.3%. According to the assessment range in Table 2, the GAP implementation in the location of this study still needs to be improved to meet the GAP requirements according to the Regulation of the Director General of Aquaculture of the Ministry of Maritime Affairs and Fisheries Number 87/2022. Therefore, some strategies are then proposed.

**Table 4.** Suitability of conditions with GAP aspects

| No. | Aspect | Real Condition | Score |
|---|---|---|---|
| 1 | Location | The location of the seaweed cultivation unit has certain zoning system. The location of aquaculture waters is in an area that is safe from potential contamination (mining, river estuaries, ports, industry, and other sources of contaminants). Producers already know that using chemicals can interfere with seaweed growth, so this aspect is minimized. However, contamination that has the potential to arise from the surrounding environment has not been handled optimally, which affect the quality of the seaweed. | 2 |
| 2 | Water supply | Producers use seawater that flows in the ponds used. The pond's location is equipped with a water control gate and filter so that physical impurities can be filtered and not enter the pond. Water quality is tested when conducting aquaculture business according to the technical requirements. The water source does not contain harmful contaminants/contaminants that can contaminate the product. | 4 |
| 3 | Layout and design | Seaweed cultivation is carried out with a combination of milkfish, crab, and shrimp at a depth of 50-100 cm, but waste disposal has not been done. | 4 |
| 4 | Cleanliness of facilities and equipment | The condition of the equipment is clean, but the hygiene of the equipment is not known with certainty and needs to be measured. Producers already understand that for clean and hygienic conditions, prevention of pests and diseases, and prevention of contamination, this is done using regular water changes and a combination of milkfish. Milkfish reduces moss, which is categorized as a pest in this cultivation. | 4 |
| 5 | Preparation of cultivation containers | The cultivation containers are made of materials that do not easily pollute the environment and are free from contaminants. Containers are well prepared, but condition checks should be carried out periodically and regularly. | 4 |
| 6 | Water management | Water filtering is done by using a sluice equipped with a filter. Water quality has been checked at the start of cultivation. Change pool water at least once weekly, and check the pH regularly. | 2 |
| 7 | Seedlings, planting, and maintenance | Aquaculture water is flowing, so there is circulation. Seedlings were obtained from nursery units in Jakarta and were in good health. Water is changed at least once every three days based on water flow from the source. | 4 |
| 8 | Harvest | The hygiene of the tools is still being determined, and the drying method is still carried out on the street (not using mats). Harvest equipment is made of materials that do not contain hazardous materials. | 3 |
| 9 | Handling results | Drying is carried out on racks, seaweed is not contaminated with fresh water, and the maximum percentage of impurities is 3%, but the separation of impurities is not routinely carried out. The dryness level of seaweed was not tested in the laboratory. | 3 |

| No. | Aspect | Real Condition | Score |
|---|---|---|---|
| 10 | Packing and storage | Packaging is according to regulations, but hygienic conditions and avoidance of cross-contamination cannot be known. They are packed with 50 kg or 40 kg capacity and stored in a room with air circulation, not damp, and covered with pallets. | 4 |
| 11 | Waste disposal | The disposal of plastic and other waste, such as shells and snails, is separated to prevent contamination, but there are no waste disposal facilities. | 3 |
| 12 | Recording and storage | The recording is done by recording incoming goods based on type, origin, and harvest date and labeled with the distance between packages and a maximum packaging height of 5 plastics. However, water quality records are unavailable, and seedlings' species/origin and age records are only sometimes available. | 2 |
| 13 | Corrective action | Producers do not take all corrective actions but perform some actions, such as routine pest cleaning and recording. | 3 |
| 14 | Training | Training is conducted periodically to increase knowledge about good seaweed cultivation. This training is usually arranged by the farmers or facilitated by the local officials. | 3 |
| 15 | Personnel hygiene | The staff's hygiene practices were still lacking, such as using improper clothes and no footwear, etc. Periodic health checks, including data recording or documentation availability, have yet to be carried out. | 4 |
| | | **Total Score** | **49** |

There are three main parameters in GAP that get a score of two or low (manufacturer knows about the requirements but performs activities only occasionally) namely related to parameter location, water management and recording and storage. The location requirement is that the cultivation business unit is in a suitable environment where food safety risks from chemical, biological and physical hazards are minimized (Regulation of the Director General of Aquaculture of the Ministry of Maritime Affairs and Fisheries Number 87/2022). The presence of pollution from the surrounding environment that has not been handled optimally has the potential to impact the quality of seaweed. These results are in line or linear with the quality test results where there are levels of lead (Pb) content, and microbial contamination (total plate count and mold/yeast) that exceed the limits.

The regulations state that water management aspects must include water filtering or sedimentation efforts and ensure water quality that is suitable for farmed fish. In addition, regular monitoring of source water quality is also carried out to ensure the health and cleanliness of the fish being farmed. The effort made by seaweed farmers is to filter the water using sluice gates equipped with filters. Water quality was checked at the start of cultivation. Change the pool water at least once a week, and check the pH regularly. However, this procedure was not carried out consistently, because the sluice gates and filters were found to be worn and damaged. Water changes are also not carried out consistently because there are no reports regarding this. This is also related to the third parameter which has a low value, namely recording and storage. Recording.

In accordance with GAP regulations, it is necessary to record the type and origin of feed, medicines, chemicals and biological materials, record water quality (source water, supply water, maintenance water and liquid waste), disease occurrences that may have an impact on product food safety, harvest and seaweed transportation. However, several aspects are not carried out by farmers, including water quality records and records of species/origin and age of seedlings which are only sometimes available.

## 4. DISCUSSION

### 4.1 Quality and GAP of seaweed

Based on the result, the important aspects to be improved on seaweed farming in Brebes Regency, among others are location, water management, and data recording and storage. The characteristics of aquatic physical, chemical, and biological parameters can be used to determine the suitability of seaweed cultivation locations [75], in particular is the location where the seaweed can receive appropriate nutrition [76]. However, the low level of public knowledge and the availability of data on the oceanography of the waters is a limiting factor in developing a seaweed cultivation business [77]. Location determination can also be carried out by considering aspects of water quality, current and wave conditions as well as the natural balance and ecological carrying capacity of the waters [78] and paying attention to the analysis of spatial location data.

Processing and water quality in a seaweed cultivation area will be directly proportional to the increased production of seaweed produced [34]. Conversely, if the water quality is not good, it can cause decreasing seaweed production. The high factor of water quality in supporting the growth of seaweed production makes it a priority for seaweed farmers to pay attention. Observing seaweed water quality factors can be done by measuring parameters such as temperature and salinity [79]. Other parameters regarding water are related to depth, brightness, temperature, salinity, dissolved oxygen, pH, Nitrate ($NO_3$), and Phosphate ($PO_4$) [80]. Apart from that, it is also necessary to avoid locations that produce pollutants and contaminants that can inhibit the growth of seaweed, such as heavy metals and other toxic compounds [80]. Production facilities and equipment that do not follow GAP can cause cross-contamination from biological, chemical, and physical contaminants such as foreign bodies in food and trigger food poisoning [80]. One of the reasons for this is because the majority of seaweed farming is carried out by small firm, based on previous research it was reported that understanding of standards or best practices related to GAP is still minimal [81]. Therefore, assistance is needed in understanding the implementation of GAP for seaweed farmers. Seaweed farmers can use the Internet of Things to monitor seaweed by stabilizing the pond environment with data obtained from sensor results that they can view on the Android application, making it easier for farmers to cultivate seaweed and help improve the quality of *Gracilaria sp*. seaweed harvest [82].

The application of bookkeeping by recording all seaweed cultivation business activities can increase the development of seaweed cultivation. Furthermore, the recording results are used for reporting and data analysis as a source for continuous improvement [83]. This can give new knowledge to support the sustainability of the seaweed cultivation. A good recording practice is important. Good records enable data tracing when required and its origins are easily known [38].

Table 3 shows the location and water management aspects got the lowest score, namely 2. This was suggested as the cause of several parameters found in Table 3, such as moisture content, heavy metal content Pb and microbial contamination (MPN and mold/yeast), exceeding the safe limit required by the guidelines. As previously explained, environmental conditions, including water, greatly determine the quality of the seaweed produced [65, 66]. The mitigation that needs to be done is to increase attention to location and water management used to minimize the risk of contamination. This process is necessary to be able to obtain dried seaweed products that comply with predetermined standards and requirements so that they will be able to increase product competitiveness. In addition, to minimize the risk of contamination at the postharvest stage (Point 9), farmers or companies are suggested to improve the drying techniques in the method and hygiene aspects to ensure good quality control of the dried seaweed.

When comparing regions or setups that do not implement Good Agricultural Practices (GAP) with those that do, several key differences emerge in terms of the quality and sustainability of seaweed cultivation. In regions where GAP is not followed, there may be a lack of standardized procedures for cultivation, harvesting, and post-harvest handling. This can lead to inconsistent quality in dried seaweed products, as well as higher levels of impurities and variability in sensory attributes. Conversely, regions or setups that adhere to GAP guidelines typically demonstrate higher levels of quality and consistency in their seaweed products. By implementing standardized practices for cultivation, including proper nutrient management, pest and disease control, and harvesting techniques, these regions can optimize seaweed growth and minimize environmental impact.

Aquaculture is one of the backbones and spearheads in implementing the industrialization program by applying GAP [84]. Current national aquaculture activities describe that most aquaculture businesses have not implemented good aquaculture practices (GAP), so their activities result in environmental degradation and cause disease problems, mass mortality, and pollution in the form of leftover feed waste and waste drug use that are not of the right type and dosage [72]. Especially for seaweed, Indonesia is one of the largest seaweed producing countries in the world [76]. Therefore, attention to the implementation of GAP in seaweed farming must be increased. Seaweed farming in this case is comprehensive for all related parties in the seaweed supply chain including farmers, local collectors, traders, exporters, manufacturers (product), and customers [81]. The Indonesian government currently has a policy regarding downstream seaweed with the aim of increasing the capacity and quality of seaweed [85]. However, several things need to be considered in seaweed farming. Apart from providing positive benefits and impacts, several researchers have reported the negative impacts of seaweed farming, including being able to disrupt ecosystem of seagrass and several coral fish [85-87] and has the potential to degrade water quality due to waste generation and heavy metal contamination from seaweed farming activities [88]. Therefore, some research in the future can be carried out, especially on farming of *Gracilaria sp.* type seaweed. in Brebes Regency. Future research that can be done are identification, especially strengths, weaknesses, opportunities, and threats (SWOT) as has been done in previous research to identify comprehensive development potential to improve the quality of seaweed produced based on GAP [89].

Overall, the adoption of GAP in seaweed cultivation not only improves product quality but also contributes to the sustainability of coastal ecosystems and the livelihoods of seaweed farmers. Regions or setups that do not implement GAP may face challenges related to product consistency, environmental degradation, and market competitiveness, highlighting the importance of standardized practices for the long-term viability of the seaweed industry.

### 4.2 Practical implications

The results of this research provide new information and knowledge regarding the level of implementation of GAP in seaweed SMEs and its influence on the quality of the products produced. Through GAP analysis, each criterion can be analyzed for sources that have the potential to cause a decrease in quality, and conversely, quality improvement can be done through increasing or improving each criterion in the GAP. The practical implication of this research is that SMEs or seaweed cultivation companies can identify or assess independently using GAP parameters, scoring, and weighting to assess each aspect of cultivation. Through this assessment, the quality of seaweed products can be maintained and improved.

Quality is the main variable related to customer satisfaction [90, 91]. Quality from the dimensions of health, safety and security is able to prevent negative risks from product use [92], such as accidents, poisoning and even death [93]. Economically, quality is a determinant for consumers to repurchase (repeat orders) or reuse products or services that have been purchased, so that consumers will be more loyal to producers [94]. Company performance can be measured through the quality of the products and services produced [95], and as an economic indicator of the production process [96]. Achieving quality products and processes in a globalized and competitive economy is one of the main strategies adopted by organizations [97].

Sustainable production is the principle of obtaining the maximum possible product while maintaining environmental sustainability [98]. Therefore, to ensure the sustainability of seaweed farming activities, future research can also be carried out to assess the sustainability of seaweed farming activities. This is to identify environmental impacts comprehensively in accordance with the ISO 14044 standard - life cycle assessment [99]. Several studies have been reported regarding life cycle assessment for seaweed farming [100, 101], so that for the location and type of seaweed, especially in Brebes Regency, it can be done to identify potential environmental impacts that are currently being carried out. The results obtained are the basis for developing better and environmentally friendly seaweed farming activities in the future with the support of technology development and sustainable management.

## 5. CONCLUSION

Brebes Regency, as one of the seaweed production centers in Indonesia, is expected to be able to produce seaweed products according to the required standards to increase the competitiveness of these seaweed products in the market. The results of testing the quality of dried seaweed produced were based on several requirements, such as SNI and BPOM Regulations, and most of them met the specifications for the required parameters. However, several parameters still exceeded the safe limit, including moisture content, impurities, heavy metal Pb, microbial contamination (TPN), and mold/yeast contamination. Parameters that do not meet these requirements can impact the quality of seaweed derivative products. This phenomenon could be related to implementing good aquaculture practices that still need improvement, particularly in determining production locations, water management, product recording, and storage. The application of good aquaculture practices (GAP), translated into CBIB, by the Ministry of Maritime Affairs and Fisheries, is a guideline that seaweed producers can implement in Brebes Regency. By implementing GAP, the quality of the dried seaweed and its derivative products is expected to meet the requirements. In addition, it can increase its value and competitiveness in the local, national, and international markets. Future research can also be undertaken to deepen the understanding of the application of GAP in seaweed farming and its long-term impact on the environment and the sustainability of seaweed farming.

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## NOMENCLATURE

| | |
|---|---|
| GAP | Good Agricultural Practices |
| TPN | Total Plate Number (microbial contamination) |
| °C | Celsius degree |
| *Spp* | Species pluralis |
| *Sp.* | Species (botany) |
| Hg | Hydrargyrum (mercury) |
| Pb | Plumbum (lead) |
| Cd | Cadmium |
| As | Arsenic |
| CAW | Clean Anhydrous Weed |
| SNI | Indonesian National Standard |
| ISO | International Standard (International Organization for Standardization) |
| VRBL | Violet Red Bile Lactose |
| EC Broth | Escherichia coli Broth |
| RVS Broth | Rappaport-Vassiliadis Broth |
| MKTTn | Muller-Kauffmann Tetrathionate Novobiocin |
| ASPW | Alkaline Saline Peptone Water |
| TCBS | Thiosulfate Citrate Bile Salts Sucrose |
| TSAT | Triphenyltetrazolium Chloride Soya Tryptone |
| XLD Agar | Xylos-Lysine-Desoxycholat Agar |
| TSIA | Triple Sugar Agar |
| LDB | L-Lysine Decarboxylase |
| dSPE | 1,2-Distearoyl-sn-glycero-3-phosphoethanolamine |
| LC-MSMS | Liquid Chromatography Tandem - Mass Spectrometry |
| $HNO_3$ | Nitric acid |
| ICP-MS | Inductively Coupled Plasma - Mass-Spectrometry |
| GMP | Good Manufacturing Practice |
| QMS | Quality Management System |
| mL | milliliter |
| µm | micrometers |
| mg/kg | milligram per kilogram |
| CFU/g | colony-forming unit per gram |
| MPN/g | Most Probable Number per gram |
| g | gram |
| % | percent |