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Implementation of Green Technopreneurship through the ATCP Method for Community-Scale Processing of Gracilaria sp. in Jabon, Sidoarjo

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ABSTRACT

Sidoarjo Regency, particularly Jabon District, is a central hub for Gracilaria sp. seaweed cultivation; however, its economic value remains low due to the dominance of raw material sales with high impurity levels. This study aims to optimize seaweed quality through the implementation of Alkali Treatment Conditioning Process (ATCP) technology using a modified High-Density Polyethylene (HDPE) tank reactor integrated with a waste mitigation system. The research method employed purposive sampling for raw material procurement, followed by alkaline treatment using 5% (w/v) NaOH solution at a biomass-to-solution ratio of 1:10 and a temperature of 60–80°C for 2–3 hours within the reactor. Environmental sustainability was addressed through the application of an active wastewater treatment plant (WWTP) using alum coagulants. The results showed measurable improvements in the quality characteristics of the Ready-to-Process (RTP) product, with an ash content of 1.24% (based on SIG lab test No. SIGS.LHP.XII.2025.081534511) and an average dry weight of 8.18 g per thallus compared with 6.97 g per thallus in the control, corresponding to a descriptive difference of 17.4%. The alum-based WWTP system reduced Total Nitrogen (N-Total) levels by 66.7%, from 1.2 mg/L to 0.4 mg/L, indicating an improvement in N-Total following wastewater treatment. This innovation offers an efficient Green Technopreneurship model for MSMEs to enhance product bargaining power in the food and pharmaceutical industrial markets.

1. INTRODUCTION

Sidoarjo Regency has considerable potential for aquaculture, with Jabon District representing one of the important centers of Gracilaria sp. cultivation in East Java. However, this potential has not been fully translated into economic benefits for the farming community in Kupang Hamlet, Tanjungsari Village. More than 80% of harvested seaweed is still distributed as raw material with relatively low hygiene and quality standards due to contamination by organic materials and physical impurities. This condition weakens farmers' bargaining position and limits access to higher-value food, pharmaceutical, and cosmetic markets. Post-harvest processing is therefore essential because Gracilaria is an important commercial source of agar, whose industrial functionality is strongly influenced by its chemical characteristics and processing conditions (Xiao et al., 2021).

Current empowerment programs initiated by government authorities and local institutions, including the Sumber Mulyo 5758 Cooperative, have primarily focused on upstream activities such as seed provision and conventional drying facilities. However, these interventions have not sufficiently addressed the biochemical transformations required to improve Gracilaria quality. One important factor affecting agar functionality is sulfate content; alkaline treatment promotes desulfation and the formation of 3,6-anhydrogalactose, thereby improving agar gel properties (Xiao et al., 2021). NaOH concentration is a critical factor in agar extraction from Gracilaria verrucosa, significantly affecting yield, gel strength, and sulfate content. Optimal alkali concentration promotes sulfate conversion and gel-network formation, thereby improving agar yield and gel strength, whereas excessively low or high concentrations can reduce agar quality (Farand et al., 2025). Empirical evidence from Yarnpakdee et al. (2015) showed that alkaline pretreatment increased agar yield from 17.1% in untreated Gracilaria tenuistipitata to 23.6–26.1%, accompanied by improved gel properties and reduced sulfate content. Similarly, Belattmania et al. (2021) reported an increase in agar yield of Gracilaria gracilis from 15.16% to approximately 20.5% following alkaline pretreatment. Nevertheless, excessive alkaline treatment may cause polysaccharide degradation and biomass loss, indicating the need to balance product quality, material recovery, and processing efficiency (Belattmania et al., 2021).

Despite these advances, previous studies have predominantly focused on optimizing alkaline pretreatment and evaluating agar yield, sulfate content, and physicochemical and gel properties under controlled processing conditions (Xiao et al., 2021). These approaches collectively support the concept of employing improved processing equipment and methods, such as hybrid washing systems, to enhance seaweed processing efficiency in both community and commercial contexts (Power et al., 2025). However, the translation of alkaline treatment into an affordable operational system for small-scale cultivators, together with appropriate management of the resulting wastewater, remains relatively limited. This issue is particularly relevant in Jabon because Gracilaria cultivation occurs within a polyculture pond ecosystem, where environmental quality is essential for production sustainability. Although While Gracilaria can contribute to bioremediation and nutrient removal in polyculture systems (Tong et al., 2025), alkaline wastewater generated during agar processing should be appropriately treated before discharge to minimize environmental impacts (Xie et al., 2024).

In the present study, ATCP consistently refers to the Alkali Treatment Conditioning Process. Although alkaline treatment is also widely applied in the processing of carrageenan-producing seaweeds, its application to Gracilaria is well established as a pretreatment for improving agar quality. In Gracilaria, alkaline treatment promotes desulfation and the formation of 3,6-anhydrogalactose, which contributes to improved agar gelling properties (Belattmania et al., 2021; Xiao et al., 2021). Therefore, the ATCP applied in this study should not be interpreted as the "Alkali Treatment Cottonii Process." Rather, it represents an operational conditioning process specifically applied to Gracilaria sp. The novelty of the present study lies not in the alkaline treatment itself, but in its integration with a modified HDPE tank reactor and wastewater management system for community-scale Gracilaria processing.

Therefore, the research gap lies in the limited implementation of an integrated community-scale system that combines alkaline conditioning, an affordable processing reactor, and wastewater management for Gracilaria processing. The novelty of this study lies in integrating the Alkali Treatment Conditioning Process (ATCP), a modified High-Density Polyethylene (HDPE) tank reactor, and an active wastewater treatment system within a Green Technopreneurship framework for small-scale Gracilaria processing in Jabon, Sidoarjo. Translating alkaline treatment from laboratory to community-scale processing can support coastal community empowerment when combined with local capacity building and environmental mitigation, thereby promoting more sustainable production practices (Hermawan et al., 2023; Kurniaman et al., 2024). Accordingly, this study aims to evaluate the implementation of the integrated ATCP–HDPE reactor system for improving the quality of Ready-to-Process Gracilaria sp. and to assess the effectiveness of the accompanying wastewater treatment system in reducing the pollutant load generated during processing.

2. METHODS

This series of studies began with the acquisition of Gracilaria sp. seaweed samples through purposive sampling from the polyculture pond ecosystem in the Jabon area, Sidoarjo, with a focus on thallus that has a chewy texture, high turgor pressure, and dense branches that are free from ice-ice symptoms to prevent degradation of the agarose polymer. The thallus then went through a manual cleaning process (pre-cleaning & sorting) to separate macro contaminants such as plastic waste and epiphytes, which aims to ensure the accuracy of the pure weight of the biomass while protecting the reactor agitation unit from mechanical damage. After cleaning, the samples were weighed using a 0.01 g precision digital scale to determine the Hydromodulus Ratio of 1:10, where every 1 kg of biomass was processed in 10 liters of alkaline solvent to ensure sufficient kinetic space for the thallus during agitation and ensure uniform saturation of the desulfation reaction through thorough penetration of hydroxide ions (OH^-). The main processing process is carried out in a modified High-Density Polyethylene (HDPE) tank reactor which is inert and resistant to strong base corrosion.

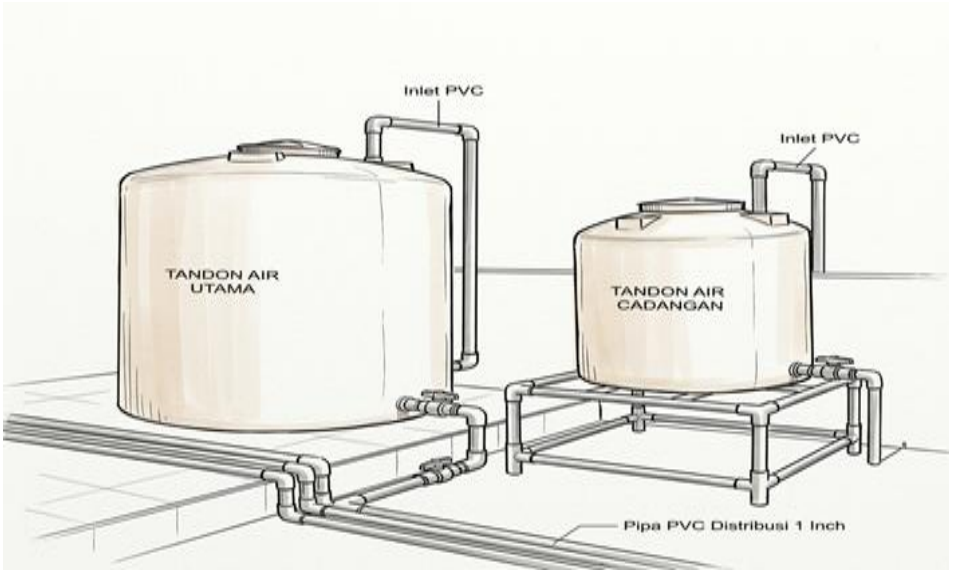

Figure 1. Modified HDPE tank reactor used for the ATCP treatment of *Gracilaria* sp.

Gracilaria sp. biomass was treated using a 5% (w/v) sodium hydroxide (NaOH) solution at a biomass-to-solution hydromodulus ratio of 1:10 (1 kg biomass:10 L solution). The NaOH concentration was selected based on previous studies demonstrating the effectiveness of alkaline pretreatment for improving the physicochemical and gelling properties of agar from *Gracilaria* spp. (Yarnpakdee et al., 2015; Xiao et al., 2021). The alkaline treatment was conducted at 60–80°C for 2–3 h, with manual agitation at 20–30 min intervals to maintain treatment homogeneity. Following alkaline conditioning, the biomass was thoroughly rinsed with clean water until the washing solution reached pH 7.0 to remove residual alkali before subsequent processing

Control Treatment

For comparison, Gracilaria sp. samples that were not subjected to the ATCP alkaline treatment were used as the control. The control samples underwent the same initial sorting and manual cleaning procedures as the ATCP-treated samples but were processed without immersion in NaOH solution. The samples were subsequently dried using the same solar drying procedure applied to the ATCP-treated samples. The average dry weight per thallus obtained from the control was used as a descriptive reference for comparison with the ATCP-treated samples.

Wastewater Treatment

Residual alkaline wastewater generated from the ATCP process was separately channeled through a PVC pipe system into a simple Wastewater Treatment Plant (WWTP) unit. Wastewater treatment was conducted using alum as a coagulant through a static settling process. Alum was added to promote the coagulation and flocculation of suspended particles, followed by settling prior to wastewater quality assessment. The effectiveness of the wastewater treatment was evaluated by measuring Total Nitrogen (N-Total) concentration before and after treatment.

The final stage of the research focused on standardizing Ready to Process output through a solar dehydration system. Seaweed was spread on a para-para unit with a minimum height of 1 meter from the ground surface to create 360-degree convective air circulation to accelerate evaporation and minimize the risk of soil microorganism contamination. During the 2–3 day drying period, a periodic thallus turning technique was performed to maintain the stability of the agarose polymer and prevent brittleness due to thermal degradation. After reaching the industry standard moisture content of 15–20%, validation of success was carried out through the calculation of the final yield.

Research Design

This study employed an applied experimental design with a quantitative descriptive approach to evaluate the implementation of the Alkali Treatment Conditioning Process (ATCP) using a modified HDPE tank reactor. Product characteristics obtained after ATCP treatment were descriptively compared with those of the control samples processed without alkaline treatment. The study also evaluated changes in Total Nitrogen (N-Total) concentration before and after wastewater treatment.

Population and Sample

The population consisted of Gracilaria sp. cultivated in polyculture ponds in Jabon District, Sidoarjo Regency. Samples were selected using purposive sampling based on good physical condition, including a chewy texture, high turgor pressure, dense branching, and the absence of visible ice-ice symptoms. The research sample consisted of Gracilaria sp. thallus selected using purposive sampling technique with the following criteria:

1. has a chewy texture
2. high turgor pressure
3. dense branches
4. free from ice-ice symptoms

Sample selection is carried out to obtain the best quality raw materials so that the ATCP process can run optimally.

Data Collection Technique

Data were collected through direct observation of the processing stages and laboratory measurements of the resulting product and wastewater. Product-quality data included ash content, average dry weight per thallus, and nutritional composition, while wastewater quality was evaluated based on Total Nitrogen (N-Total) concentration before and after treatment.

Data Analysis Technique

The data obtained in this study were analyzed descriptively based on laboratory measurements and comparisons between the ATCP-treated samples and the control, as well as wastewater conditions before and after treatment. The evaluated parameters included ash content, average dry weight per thallus, nutritional composition, and Total Nitrogen (N-Total). Changes in average dry weight and N-Total were expressed as percentage differences to facilitate descriptive comparison between conditions. Because individual replicate data were not available for inferential statistical analysis, the results were interpreted descriptively, and no statistical significance was inferred from the observed differences.

3. RESULTS

The implementation of the Alkali Treatment Conditioning Process (ATCP) using a modified HDPE tank reactor resulted in measurable differences in the quality characteristics of Gracilaria sp. produced in Jabon, Sidoarjo. Based on validation by a KAN-accredited laboratory (Certificate No.

SIGS.LHP.XII.2025.081534511), the Ready-to-Process product had an ash content of 1.24%, as determined according to SNI 2354.1:2010, which remains the current applicable Indonesian National Standard for ash determination in fishery products (Badan Standardisasi Nasional, 2010).

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No	Parameter	Unit	Simplo	Duplo	Limit Of Detection	Method
1	Energi Total	Kcal/100 g	35.00	36.08	-	11-3-3/MU (Perhitungan)
2	Energi Dari Lemak	Kcal/100 g	0.00	0.00	-	11-3-3/MU (Perhitungan)
3	Kadar Abu	%	1.24	1.25	-	SNI 2354.1 : 2010
4	Kadar Air	%	90.01	89.73	-	SNI 2354.2 : 2015
5	Karbohidrat (By Difference)	%	7.53	7.84	-	11-3-3/MU (Perhitungan)
6	Kadar Lemak Total	%	<0.02	<0.02	-	11-3-2/MU (Weibull)
7	Kadar Protein	%	1.22	1.18	-	11-3-1/MU (Titrimetri)

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Figure 2. Results of seaweed lab tests

This value indicates a very high level of purity because it is far below the industrial standard threshold, while also proving the effectiveness of the manual agitation system in the HDPE reservoir reactor to completely remove micro-contaminants. Further proximate analysis showed a protein content of 1.22%, a carbohydrate content (by difference) of 7.53%, and a reported total energy value of 35.00 kcal/100 g. The reported energy value is consistent with the energy contribution of carbohydrate and protein using conversion factors of 4 kcal/g for each macronutrient. From a physical perspective, the ATCP-treated samples had an average dry weight of 8.18 g per thallus, compared with 6.97 g per thallus in the control, corresponding to a 17.4% higher average dry weight. This descriptive difference indicates better retention of thallus mass under the applied ATCP conditions.

In addition to product quality aspects, the management of residual liquid waste from the alkali process, which is channeled independently through a PVC pipe installation to a simple wastewater treatment unit, is a crucial component in the sustainability of this process. The N-Total concentration decreased from 1.2 mg/L before wastewater treatment to 0.4 mg/L after treatment, corresponding to a descriptive reduction of 66.7%. This result indicates a decrease in N-Total following the applied wastewater treatment process.

Overall, the innovative production unit using modified HDPE tanks offers an affordable yet high-performance Green Technopreneurship solution for MSMEs. The use of HDPE material ensures long-term resistance to strong base (NaOH) corrosion, while the transformation of raw materials into low-ash RTP products significantly increases the commodity's bargaining power. The striking visual difference between seaweed before and after the ATCP process can be seen in Figure 3, where the final product exhibits a higher level of thallus cleanliness and brighter color compared to the raw material.

COMPARISON BEFORE AND AFTER WASHING USING THE ATCP METHOD

Before Wastewater Treatment	**After Wastewater Treatment**
	

Figure 3. Physical appearance of Gracilaria sp. before and after ATCP treatment

The success of the ATCP method in removing physical and micro contaminants is visually shown in the image above, where the thallus of the product ready for processing looks much cleaner, brighter, and free from mud compared to the condition of the raw material before treatment.

4. DISCUSSION

The results of the study showed that the implementation of Alkali Treatment Conditioning Process (ATCP) technology using a modified HDPE tank reactor was associated with improvements in the measured quality characteristics of Gracilaria sp. The quality improvement was seen from the low ash content of 1.24%, indicating the success of the micro-contaminant cleaning process and residual impurities in the seaweed thallus. This value is below the general industry standard so that the resulting product has greater potential to enter the food and pharmaceutical industry markets. The average dry weight was 8.18 g per thallus after ATCP treatment compared with 6.97 g per thallus in the control, representing a descriptive difference of approximately 17.4%. Although inferential statistical analysis could not be performed due to the absence of individual replicate data, the observed difference provides preliminary evidence of improved mass retention under the applied processing conditions.

This condition supports previous research which stated that the use of NaOH with the right concentration and temperature can improve the quality of agar and gel strength in Gracilaria sp. In addition, the use of HDPE reactors has proven effective because the material is resistant to alkali corrosion so that the production process can run more stably and efficiently. From an environmental perspective, the N-Total concentration decreased from 1.2 mg/L before wastewater treatment to 0.4 mg/L after treatment, corresponding to a 66.7% reduction. This finding indicates an improvement in N-Total following the applied wastewater treatment process. However, N-Total represents only one parameter of wastewater quality and is insufficient to establish the overall environmental safety of the treated effluent. Further evaluation of parameters such as COD, TSS, and final effluent pH is therefore required to comprehensively assess the environmental performance of the wastewater treatment system.

The implementation of the Green Technopreneurship concept through ATCP provides an opportunity for seaweed farming MSMEs in Jabon District to produce higher-quality Ready-to-Process products rather than selling untreated raw materials. This product upgrading may potentially improve the added value and bargaining position of seaweed cultivators in the industrial market. However, economic parameters such as production costs, selling prices, revenues, and profit margins were not quantitatively evaluated in this study. Therefore, further economic analysis is required to determine the actual financial benefits of ATCP implementation at the community scale.

5. CONCLUSION

Based on the results of the research and discussion, it can be concluded that the implementation of Green Technopreneurship technology through a modified HDPE reservoir reactor and a simple WWTP system is effective in improving the quality of Gracilaria sp. seaweed in Jabon, Sidoarjo. Transformation through the Alkali Treatment Conditioning Process (ATCP) method integrated with an independent agitation unit successfully produced a Ready to Process product with an Ash Content of 1.24%. This value has been validated through laboratory tests numbered SIGS.LHP.XII.2025.081534511 using the SNI 2354.1:2010 method. Physically, the use of this reactor was able to produce an average dry weight of 8.18 g per thallus, which shows an increase compared to the control method of 6.97 g.

In addition to product quality aspects, the liquid waste management system using alum coagulant and multi-stage filtration has proven to be environmentally friendly with the ability to reduce Total Nitrogen (N-Total) levels by 66.7%, namely from an initial concentration of 1.2 mg/L to 0.4 mg/L. This independent tool design innovation provides an efficient, appropriate technological solution for MSMEs to increase the bargaining value of seaweed commodities in the food and pharmaceutical industry markets.

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