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Integrated Shrimp Aquaculture Wastewater Treatment and Cultivation of Microalgae Isolated from Mining Area

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Abstract

Microalgae have a high lipid content, making them a potential feedstock for biofuel production. In this study, microalgae isolated from the Tanggamus mining area was cultivated in liquid medium from shrimp aquaculture waste. The main objectives were to examine the growth of microalgae in shrimp aquaculture waste specifically in liquid waste, sediment waste, and a combination of both to assess whether these waste types can serve as effective cultivation media, and to evaluate the microalgae's adaptability as well as its role in mitigating environmental pollution. The microalgae were cultivated in the three different waste mediums, and the results were compared to a control medium using walne. The findings revealed that shrimp aquaculture sediment supported the highest biomass production, reaching 17.80 mg/L. The mixed media yielded 15.93 mg/L, while the walne control and liquid waste media produced 9.00 mg/L and 3.87 mg/L, respectively. Furthermore, post-cultivation analysis revealed an increase in nutrient concentrations, including nitrogen, phosphorus, and potassium, in the cultivation medium. The microalgae strain reduced BOD in shrimp aquaculture waste, especially in sediment. COD in liquid waste increased due to complex compounds and cell lysis. Lipid extraction from the microalgal biomass highlighting its potential as a feedstock for biodiesel production. These results suggest that shrimp aquaculture waste, particularly its sediment component, not only serves as a suitable medium for cultivating microalgae, but also contributes to environmentally sustainable practices by helping reduce aquatic pollution and promoting waste-to-resource conversion.

Keywords: Biomass; Lipid, Microalgae; Shrimp aquaculture waste

1. Introduction

In recent years, shrimp farming has grown significantly worldwide, particularly in Southeast Asia. Indonesia is one of the world's largest shrimp producers, with shrimp farming divided into intensive, semi-intensive, and extensive farming. Sebalang Village, Kalianda, is one of the villages engaged in shrimp farming activities. According to data from the Central Statistics Agency (BPS) in 2023, the production of Vannamei shrimp farming reached 14,843.59 tons in South Lampung [1], an increase from 2020, which only reached 13,906.35 tons. The data shows a fairly rapid growth in shrimp farming over the past three years in South Lampung.

On the other hand, the increase in shrimp farming activities has negative effects, namely environmental pollution. Excessive shrimp farming activities will inevitably lead to environmental degradation, such as water quality deterioration [2]. Environmental issues arise due to the management of shrimp farming areas that do not consider the environment's capacity to support the sustainability of surrounding ecosystems. The wastewater treatment unit functions to settle shrimp waste residues and chemical treatments during the shrimp harvesting process. Improper management can cause additional environmental issues that affect the entire area over an extended period.

The Tanggamus region in Lampung Province is known for its mining activities, such as gold and rock mining. These mining activities also exert pressure on aquatic environments, both physically and chemically [3]. Mining-related pollution can include increased heavy metal content, sedimentation, and deterioration of water quality, which affects aquatic organisms [4]. These conditions disrupt the ecological balance of aquatic systems and gradually reduce the

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local environment's carrying capacity, making it less able to support aquatic life and maintain water quality. If left unmanaged, such imbalances can lead to long-term environmental degradation, biodiversity loss, and the deterioration of ecosystem services. Therefore, efforts to restore water quality and manage waste must be carried out using effective, environmentally friendly, and sustainable approaches.

These extreme conditions present a challenge for the growth of most organisms; however, certain microalgae possess the ability to adapt and thrive in such environments. These microalgae are known as acidophilic microalgae. Acidophilic microalgae are a group of microalgae capable of tolerating and growing optimally under low pH conditions. These microalgae have undergone physiological and genetic adaptations that enable them to survive in acidic environments characterized by high heavy metal concentrations [5]. Algae inhabiting the waters surrounding gold mines are hypothesized to possess resistance to contaminants [6].

The growth of microalgae depends on two essential nutrient categories which include micronutrients and macronutrients. Microalgae require nutrients present in their growing medium for proper development and growth [7]. Macronutrients including nitrogen (N), phosphorus (P), and carbon (C) along with chlorophyll and proteins and nucleic acids and biomass must be present in microalgae to sustain their production of photosynthetic chemicals. The survival of enzyme activity and cellular metabolism depends on small quantities of iron (Fe) and magnesium (Mg) and manganese (Mn) and zinc (Zn) and copper (Cu) as micronutrients. Any deficiency or nutrient imbalance in these essential nutrients will cause reduced growth together with the accumulation of specific metabolites [8].

The nutrient content in shrimp aquaculture waste contains significant amounts of nitrogen together with phosphorus and organic carbon which enables resource recovery potential [9]. Shrimp aquaculture wastewater contains substantial amounts of nitrogen and carbohydrates [10]. Microalgae can thrive on these nutrients to produce valuable compounds which include lipids alongside pigments and bioactive metabolites. conversion of shrimp aquaculture waste into microalgae culture medium operates as a sustainable waste management system which produces economically valuable products. The produced compounds from shrimp aquaculture waste serve multiple uses such as food and nutrition [11], food additive [12], various sectors in manufacturing (e.g paper [13] and textile [14]), cosmetic applications [15] and pharmaceutical [16] uses as well as nutraceutical [16]-[18], bioethanol [19] and biofuel production [20]. Microalgae is also able to degrade polypropylene microplastics [21].

The microalgae used in this research was isolated from the mining area and it is likely to have resistance to extreme environments, making it a potential candidate for treating waste from shrimp farming. Thus, this study aims to explore the utilization of shrimp aquaculture waste from Tarahan Village as a growth medium for microalgae isolated from the Tanggamus mining area, as an effort toward bioremediation and sustainable production of microalgae biomass.

2. Materials and Method

2.1. Isolation of Microalgae from mining area liquid samples

Liquid samples were obtained from a mining area in Tanggamus for the isolation of microalgae. The isolation process involved aeration and incubation of 150 mL of liquid samples with 30 mL of Walne medium in a 250 mL Erlenmeyer flask at room temperature under 12-h light/12-h dark cycle. This mixture served as the initial culture environment, designed to encourage the growth of a diverse range of microalgal species present in the sample. Light-emitting diodes (LEDs) 32 watt were used as the light source. After 14 days of aeration, the culture was inoculated on solid media. The isolated microalgae was then characterized morphologically.

2.2. Shrimp aquaculture liquid and sediment waste

Shrimp aquaculture waste was obtained from Sebalang Village, Lampung Selatan a coastal settlement well known for its established shrimp farming industry. Prior to being sent to the external laboratory for analysis, one liter of fresh liquid waste and one liter of fresh sediment waste from shrimp aquacultures were carefully collected and placed into separate, clean jerry cans to prevent cross-contamination. The samples represented the pre-cultivation condition of the waste. For the post-cultivation stage, an equal volume of one liter each of treated liquid and sediment waste was collected from the culture systems after microalgae cultivation. These samples were also stored in separate, clearly labeled containers to ensure proper identification and traceability throughout the analytical process. All prepared samples were then promptly transported to the external laboratory under controlled conditions to preserve their integrity and ensure accurate measurements of the specified parameters.

2.3. Experimental Design and Analytical Methods

The isolated microalgae strain was cultivated in 250 mL Erlenmeyer containing liquid medium with aeration. Four treatment groups were established to evaluate the effect of the concentration of vannamei shrimp farming waste, namely a mixture of Walne fertilizer and shrimp pond effluent (1:1), Walne fertilizer and shrimp pond sediment (1:1), and Walne fertilizer, shrimp pond effluent, and shrimp pond sediment (1:1), with one group serving as the control group containing Walne solution. The experimental design followed a completely randomized design (CRD) with three replications for each treatment to ensure statistical reliability. Each replicate was carefully monitored under consistent experimental conditions to minimize variability.

The harvesting procedure for isolated microalgae strain was initiated after 15 days of cultivation, marking the transition from the growth phase to biomass recovery. Following cultivation, the culture mixture was stirred for a predetermined mixing period to ensure homogeneity and facilitate separation, after which it was left undisturbed overnight to allow natural sedimentation of the algal cells. The filtrate was analyzed for parameters such as COD, BOD, nitrogen, phosphorus, and potassium levels, as well as the organic carbon ratio. The analysis was conducted at the Integrated Laboratory Unit (UPT Lab Terpadu) of the University of Lampung. The results of the shrimp pond waste analysis before and after cultivation are presented in **Table 1.** The supernatant was carefully removed from the upper layer using a pump to avoid disturbing the settled biomass, and the concentrated solid phase at the bottom was transferred onto filter paper to remove residual moisture. The biomass on the filter paper was then dried in an oven at 50^{o}C temperature for 30 minutes with repetition until a constant weight was achieved, ensuring complete moisture removal and allowing for accurate determination of the dry biomass yield without compromising its quality. Productivity (mg) was determined based on the biomass yield using the following formula:

$$Dry\ weight = B_f - B_0 \quad (1)$$

where B_f is final amount of biomass (mg), and B_0 is filter paper weight.

The harvesting procedure yield was then calculated by weighing the dry biomass that remained. Lipid content was measured using the gravimetric method. A total of 20 mg of dry microalgae biomass was added to 4 mL of methanol and 4 mL of n-hexane, then vortexed for 5–10 seconds. After that, 2 mL of distilled water was added and vortexed again for 5–10 seconds. The mixture was then centrifuged at 5000 rpm for 5 minutes to separate the solid and liquid phases. Centrifugation separates components based on density, with solid particles settling at the bottom of the tube and the liquid (supernatant) remaining at the top. The supernatant phase is collected as the extraction product, while the solid residue is washed with distilled water and centrifuged again to obtain any remaining supernatant that may still be present.

The extracted lipid was subjected to analysis to determine its yield, providing a quantitative measure of lipid content from the biomass. Upon extraction, the sample exhibited three distinct phases: a polar phase containing hydrophilic compounds, a non-polar phase representing the extracted lipid, and a residual biomass phase. The non-polar phase, containing the lipids of interest, was carefully collected and transferred into a clean, pre-weighed watch glass. The collected non-polar fraction was then allowed to stand at room temperature to enable complete solvent evaporation under ambient conditions, minimizing thermal degradation of the lipid. Once the solvent had fully evaporated, the remaining lipid residue was weighed to obtain the final weight. The lipid yield percentage was subsequently calculated based on the difference between the initial and final weights, relative to the original biomass, thus providing an assessment of lipid recovery efficiency.

$$Yield = \frac{crude\ lipid\ mass}{dried\ weight\ biomass} \times 100\% \quad (2)$$

3. Results and Discussion

3.1. Microalgae strain isolated from mining area

The microalgae was isolated from the mining area of Tanggamus to obtain strain with the potential for growth and adaptation in specific environmental conditions. During the isolation phase, a nutrient-rich medium was required to support microalgal proliferation. Walne medium was selected due to its well-balanced composition of macronutrients, trace metals, and essential vitamins. Walne medium also contains chemical compounds such as phosphate and nitrate, which serve as primary nutrient sources, supporting photosynthesis, cell division, and overall biomass production. The combination of these components provides a balanced and enriched environment, ensuring optimal growth and physiological performance of the microalgae strain.

Aeration was maintained continuously for seven days using an aerator to ensure proper gas exchange and nutrient distribution, while illumination was provided by fluorescent lamps operated on a 12-hour light and 12-hour dark cycle to simulate natural photoperiod conditions. At the end of the seven-day isolation period, visible microalgal growth was observed. On solid medium, the colonies exhibited distinct morphological characteristics, including the presence of dark spots and filamentous structures, which served as preliminary indicators of microalgal diversity and vitality prior to further microscopic identification.

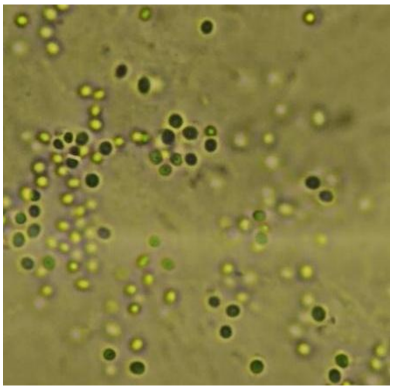

Figure 1. Light microscope image of algae obtained during the cultivation process.

Following the isolation phase, the chosen isolates were inoculated from the liquid broth into the solid agar medium. This was carried out via the pour plate method, in which a one-milliliter of aerated water was introduced into a Petri dish containing the agar medium using a micropipette, and then distributed evenly by swirling in a figure-eight pattern. Incubation was subsequently performed in an incubator at a temperature of 30°C for five consecutive days.

To determine the type of colonies that appeared on the solid medium, identification was conducted using a binocular microscope at 100× magnification. Based on **Figure 1.** morphological observations revealed that the isolates suspected characteristics consistent with the genus *Chlorella sp. Chlorella sp.* is a microalgae commonly found in freshwater environments [22], known as a green alga with a spherical or slightly oval shape and a single chloroplast that nearly fills the entire cell [23]. For microalgae originating from mining areas, *Chlorella sp.* is capable of surviving in acidic conditions with a pH range of 1.5 to 4 and can divide into four cells without the use of flagella [24].

Various microalgae are found in environments such as mining areas, demonstrating unique adaptive capabilities. These microalgae are able to survive in toxic conditions and even absorb heavy metals from the environment through bioaccumulation and biosorption processes [24]. Mine drainage can be highly acidic and contain significant levels of potentially toxic elements (PTEs), particularly arsenic, which is one of the most dangerous elements in the environment. PTEs damage the ecosystem's balance and raise concerns about human and animal welfare. Some algae species found naturally in mine drainage waters, such as Spirogyra sp. and *Chlorella sp.*, are capable of absorbing PTEs from wastewater and may live in severe settings [25].

3.2. Result of external testing

Standard aquaculture operations in Sebalang generate substantial amounts of waste, consisting of fine silt and liquid effluent discharged from active shrimp aquacultures. These by-products are often rich in nutrients yet present environmental disposal challenges. The collected waste materials served as the primary growth medium for isolated microalgae strain. This approach allowed the researchers to evaluate not only the feasibility of reusing shrimp aquaculture waste as a culture medium but also its impact on biomass productivity and the overall sustainability of the cultivation process. To determine the composition of compounds before and after the cultivation process in shrimp aquaculture waste, a comprehensive analysis was conducted on both liquid and sediment waste samples with the assistance of an accredited external laboratory. The investigation targeted a range of key physicochemical parameters, including organic carbon (C-organic), total nitrogen (N-total), phosphate, potassium, Chemical Oxygen Demand (COD), and Biological Oxygen Demand (BOD). These parameters were selected because they provide critical insights into the nutrient profile and organic pollutant load of the waste, both of which directly influence the suitability of the medium for microalgal growth and its potential for sustainable reuse.

The analysis was conducted at the Integrated Laboratory Unit (UPT) of the University of Lampung, a facility equipped with specialized instruments and standardized procedures to ensure precise and reliable measurements. The purpose of this analysis was to evaluate the physicochemical properties and nutrient composition of shrimp aquaculture waste samples. The results, which detail the composition of both liquid and sediment waste before and after a 15-day cultivation period of microalgae isolate are summarized in **Table 1**. These findings serve as an essential reference for assessing the impact of microalgal cultivation on nutrient dynamics and pollutant reduction in aquaculture waste.

Table 1. Result of Testing from Shrimp aquaculture Waste Sample Before and After Cultivation

Sample	**Parameter of the Test**	**Result**		**Method of Testing**
		Before	**After**	
Liquid Waste of Shrimp aquaculture	N (mg/l)	0.0008	0.223	SNI 01-2354.4-2006
	P (mg/l)	0.152	326.1	EPA 200.7 Rev 5 2001
	K (mg/l)	4.28	72.3	EPA 200.7 Rev 5 2002
	COD (mg/l)	71.6	158	SNI 6989.2 : 2009
	BOD (mg/l)	37.2	17	SNI 6989.72 : 2009
	C-Organic (mg/l)	0.0072	0.36	SNI 7724:2011
Sediment Waste of Shrimp aquaculture	N (mg/l)	0.04	0.053	SNI 01-2354.4-2006
	P (mg/l)	1.444	3.67	EPA 200.7 Rev 5 2001
	K (mg/l)	5.32	12.9	EPA 200.7 Rev 5 2002
	COD (mg/l)	1020	213	SNI 6989.2 : 2009
	BOD (mg/l)	147.6	35	SNI 6989.72 : 2009
	C-Organic (mg/l)	0.676	0.25	SNI 7724:2011

3.3. *Effect of Growth Media on Biomass*

Shrimp aquaculture waste, both in liquid and sediment forms, exhibits physicochemical characteristics that reflect a high load of organic and inorganic pollutants due to intensive aquaculture activities. Liquid waste from shrimp aquacultures typically contains high concentrations of ammonia (NH_3/NH_4^+) and nitrate (NO_3^-) [26], primarily derived from uneaten feed particles that decompose in the water column as well as from shrimp excretions. These nitrogenous compounds can accumulate rapidly under high-density farming conditions, leading to potential toxicity if unmanaged. In addition, phosphate (PO_4^{3-}) levels are also considerably elevated, largely due to the residual buildup of fertilizers, mineral supplements, and feed additives applied during aquaculture maintenance. Such nutrient enrichment not only affects water quality within the aquaculture but also poses a risk of eutrophication when discharged into surrounding aquatic ecosystems. A wide range of culture conditions influence microalgal growth, including light intensity, pH, salinity, nutrition availability, temperature, CO_2, and dissolved oxygen content. As a result, these culture parameters should be tuned to increase biomass productivity [27].

Table 2. Biomass production after 15 days cultivation

Medium	Biomass Production (mg)
Liquid Waste	3.867
Sediment Waste	17.800
Combination Liquid and Sediment Waste	15.933
Control	9.000

The research results showed that the growth of microalgae isolate in untreated shrimp aquaculture wastewater resulted in the lowest biomass weight compared to other media treatments. The dry biomass obtained from this medium was only 3.87 mg/L, whereas the control medium with Walne media produced 9.00 mg/L, the shrimp aquaculture sediment medium yielded 17.80 mg/L, and the mixed medium produced 15.93 mg/L of biomass. Although shrimp aquaculture wastewater generally contains essential nutrients such as nitrogen and phosphorus [28], these results indicate that the availability or proportion of nutrients in the wastewater is insufficient or unbalanced to support optimal microalgal growth [29]. Therefore, the utilization of shrimp aquaculture wastewater as a culture medium requires further and more detailed evaluation of its nutrient composition to determine its suitability for sustained microalgal growth.

The microalgae isolate exhibited relatively good growth when cultivated in a medium based on shrimp aquaculture sediment waste, yielding a biomass weight of 17.80 mg/L. This result indicates that although it is a type of waste, shrimp aquaculture sediment still contains sufficient macronutrients such as nitrogen and phosphorus to support microalgal growth. These nutrients originate from the accumulation of uneaten feed, shrimp feces, and other organic materials settled at the bottom of the aquaculture [30]. The relatively stable characteristics of sediment waste in terms of pH and temperature, along with the potential for lower heavy metal content, make this medium more favorable compared to liquid waste, which tends to experience broader contamination [31]. Therefore, utilizing shrimp aquaculture sediment waste as a culture medium not only produces promising biomass yields but also represents a practical approach to the sustainable management of organic waste. By repurposing nutrient-rich sediments that would otherwise contribute to environmental pollution, this method aligns with eco-friendly bioconversion and bioremediation strategies aimed at reducing waste discharge into aquatic ecosystems.

The mixed medium composed of shrimp aquaculture wastewater and sediment presents a complex environmental matrix in terms of both nutrient composition and physicochemical conditions [32]. In this study, the microalgae isolate cultivated in the mixed medium demonstrated relatively high growth, with a biomass dry weight of 15.93 mg/L. Organic compounds from the sediment supported carbon availability, while the aquaculture water provided dissolved nutrients that could be readily absorbed. This mixed medium can be categorized as a potential culture substrate, although further optimization such as control of solid content ratio and pH is still necessary. Utilizing this combination medium also reflects a sustainable approach to shrimp aquaculture waste management, as it leverages two types of waste simultaneously without requiring expensive pretreatment processes. This supports the principle of resource efficiency and opens opportunities for cost-effective and environmentally friendly field-scale microalgae cultivation systems.

The favorable growth of microalgae isolate in Walne medium indicates its ability to adapt to a balanced nutrient composition, particularly the nitrogen-to-phosphorus ratio, which plays a crucial role in the formation of chlorophyll, proteins, and nucleic acids [33]. The use of synthetic media such as Walne medium in microalgae cultivation is considered more practical due to its complete nutrient profile compared to organic media [34]. In Walne medium, there are 100.09 g/L N ($NaNO_3$) and 20 g/L P (NaH_2PO_4) [32]. Additionally, Walne medium contains micronutrients such as Fe, Cu, Co, Zn, and Mn [35]. The nutrients essential for microalgae growth are presented in **Table 3** [36].

Table 3. Nutrient requirements of microalgae

Nutrient Content	Concentration (g/L)
N	0,14-0,7
P	0,01-0,62
K	0,095-3,9
Ca	0,02-0,129
Mg	0,024-0,96
Mn	0,00055-0,55
Cu	0,00000064-0,064
Fe	0,00112-0,056
Zn	0,00065-0,65

The application of Walne medium promotes better growth of green microalgae than Guillard medium, owing to its higher nutrient concentration [37]. This suggests that Walne medium can maintain the stability of microalgal cultures over an extended period.

3.4. Influence of Culture Media on Lipid Yield (%) from Microalgae Cultivated in Shrimp aquaculture Waste

This study aimed to evaluate the effect of different shrimp aquaculture waste-based media liquid waste, sediment waste, and a combination of both on the lipid yield (%) of the isolated microalgae [38]. Lipid extraction was carried out using a solid–liquid extraction method with a mixture of n-hexane and methanol as solvents, targeting the separation of non-polar (lipid) and polar (aqueous) phases. The process involved vortexing, centrifugation, phase separation, and drying of the non-polar phase, followed by gravimetric analysis to determine lipid content. The highest lipid yield was recorded in the control group cultured with Walne media at 57.78%, confirming the effectiveness of balanced synthetic nutrients. Biomass yield is determined light intensity and carbon dioxide are prominent factors [39].

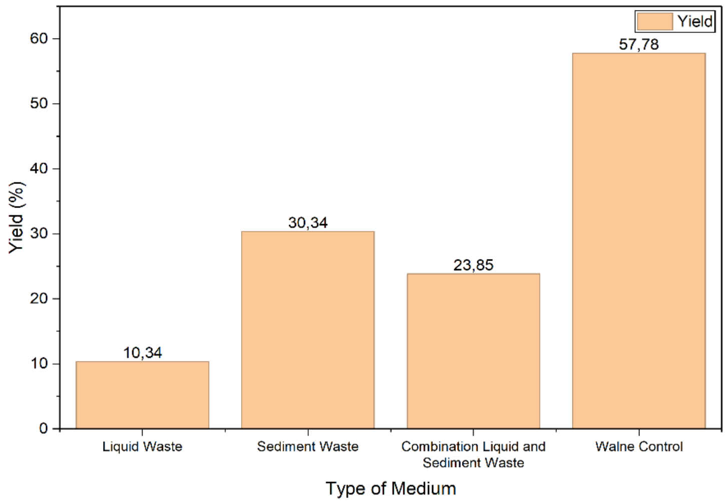

Figure 3. Total yield produced after 15 days cultivation

Although sediment waste contains more concentrated nutrients, its semi-solid nature limits nutrient availability due to diffusion constraints. Conversely, liquid waste is more readily available but nutritionally insufficient, while the mixed medium presents a balanced but still suboptimal environment. Nutrient analysis revealed an increase in nitrogen, phosphate, and potassium levels after cultivation, indicating biological transformation and nutrient recycling processes. For example, nitrogen concentration in liquid waste increased from 0.0008 to 0.223 mg/L, phosphate from 0.152 to 326.1 mg/L, and potassium from 4.28 to 72.3 mg/L. These increases are attributed to the activity of microalgae. in metabolizing available compounds and possibly the lysis of algal cells, which releases intracellular nutrients [40].

The microalgae isolate demonstrated good adaptability to the tested waste media, particularly under nitrogen-limited conditions, which triggered lipid accumulation as a stress response. Nitrogen deficiency inhibits cell division but enhances lipid biosynthesis, especially in the stationary growth phase, where energy storage becomes a priority [41]. When microalgae encounter nitrogen starvation, they can no longer synthesize essential proteins and nucleic acids required for cellular replication, forcing cell division to halt and transitioning the culture into the stationary growth phase. With growth arrested, the cells redirect the excess carbon fixed during photosynthesis away from structural components and toward energy storage pathways. Consequently, metabolic flux is channeled into the intensive biosynthesis of neutral lipids, primarily triacylglycerols (TAGs), which accumulate in specialized intracellular lipid bodies as dense energy reserves. This metabolic shift serves as a vital survival mechanism, allowing the organism to endure prolonged environmental stress until favorable nutrient conditions return. Lipids synthesized under these conditions serve as an energy reserve [40] and are composed of saturated and unsaturated fatty acids synthesized in the chloroplast stroma. These findings are consistent with previous studies indicating that microalgae accumulate higher lipid content under nutrient stress, especially nitrogen limitation [42].

The results also underline the potential of microalgae isolate as a sustainable and efficient source of biodiesel [38]. Compared to terrestrial crops, microalgae have a lipid productivity that is up to ten times higher, require less land, do not compete with food resources, and can be cultivated using various types of water, including wastewater [43]. The integration of shrimp aquaculture waste as a cultivation medium not only provides a low-cost and environmentally friendly nutrient source but also contributes to waste management and bioconversion efforts. This dual benefit positions microalgae-based biodiesel as a promising alternative energy source in the pursuit of renewable and sustainable fuel options [44].

3.5. The Effect of COD and BOD Content on Microalgae Growth in Shrimp Farm Wastewater

The data in **Table 1** shows the effectiveness of isolated microalgae strain cultivation in reducing organic pollutant levels in liquid waste and shrimp aquaculture sediments. This study analyzed the changes in Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD) in shrimp aquaculture wastewater both liquid and sediment before and after the microalgae isolate cultivation. The initial COD and BOD levels indicated high organic pollution, with sediment waste showing notably higher values than liquid waste. After cultivation, BOD levels in sediment waste decreased significantly, attributed to the microalgae's ability to utilize readily degradable organic matter as a carbon and energy source for biomass synthesis. This reduction aligns with previous findings that microalgal activity can lower COD by consuming organic compounds, thereby supporting cell growth [45].

In contrast, the liquid waste medium exhibited a COD increase despite a decrease in BOD. This rise was linked to the metabolic release of complex organic compounds such as polysaccharides such as exopolysaccharides (EPSs) [46], proteins, and secondary metabolites, which are more resistant to chemical oxidation and biological degradation [47]. Additionally, cell lysis caused by limited aeration or nutrient depletion released intracellular organics into the medium, further increasing COD. These findings suggest that while microalgae are effective in reducing BOD, they can also contribute to COD accumulation through the excretion of complex metabolites and cell lysis [45]. Suboptimal environmental conditions, such as minimal aeration or limited nutrients, can accelerate microalgal death and deteriorate water quality. Effective culture management, including optimal aeration and nutrient availability, is therefore crucial to minimizing COD build-up while maintaining the benefits of BOD reduction in microalgal-based wastewater treatment [48].

4. Conclusions

This study was carried out to determine the potential of shrimp aquaculture waste as a medium for the cultivation of microalgae. Sediment waste from shrimp aquacultures provides an excellent medium for microalgae growth, producing a dry biomass weight of 17.8 mg/l, higher than that produced by liquid waste from shrimp aquacultures. The highest lipid content was obtained from Walne medium (57.78%) and shrimp aquaculture sediment waste (30.34%). Microalgae exhibited good adaptive capacity in reducing contamination in shrimp aquaculture sediment waste, as indicated by a decrease in biochemical oxygen demand (BOD) and chemical oxygen demand (COD). For liquid waste, however, biochemical oxygen demand (BOD) and chemical oxygen demand (COD) increased due to cell lysis. This can be triggered by insufficient aeration or limited carbon sources, contributing to an increase in COD values. The lysis process causes the release of complex organic compounds from inside the cells into the medium, thereby increasing the load of organic pollutants.

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