

The Potential of Local Microalgae Isolates in Biotechnological Applications

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ABSTRACT

Microalgae biofilms have emerged as a promising candidate in biotechnology, including enhancing biomass production for various applications and as an efficient alternative to conventional wastewater treatment. This study explores the potential of local microalgae in reducing pollutants in wastewater by sequestering nitrogen and phosphorus while generating biomass that can be used for human food and animal feed. Local microalgal isolates are known to have potential in offering cost-effective, efficient, and sustainable nutrient removal while enabling resource recovery and minimizing ecological risks in wastewater treatment. A total of eight microalgal biofilm samples were successfully isolated and preliminarily identified. Three were from the Chlorophyta group, one was Cyanobacteria while the other belonged to the Ochrophyta group. Highest biomass yield was produced by isolate MA12 at a 90.0% increase in wet weight mg/L, followed by 76.9% and 70.0% by MA22 and MA19, respectively. When grown in synthetic wastewater for seven days, the highest reduction in TN was observed in MA18 at 43.5% while MA7 showed a remarkable performance of 95.0% of reduction of TP. Integrating microalgae biofilms into wastewater treatment systems can thus enhance pollutant removal and contribute to the circular economy by converting waste into valuable bioproducts. This study highlights the novelty of using local microalgae isolates both in environmental protection and resource recovery, paving the way for their implementation in sustainable wastewater management practices.

INTRODUCTION

Rapid urbanisation, industrialisation, and agricultural practices have resulted in nutrient-rich wastewater that is high in nitrogen (N) and phosphorus (P), making wastewater management an increasingly pressing

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global issue. These nutrients lead to eutrophication, which damages aquatic ecosystems and results in toxic algal blooms and oxygen deprivation. These nutrients are frequently difficult for conventional treatment technologies to completely remove, and their high energy requirements, chemical use, and problems with sludge disposal raise questions regarding sustainability. To manage nutrient pollution and achieve global objectives like clean water availability and ecosystem protection, efficient, affordable, and environmentally friendly solutions are essential (Li et al., 2025; Saini et al., 2023; Sriram & Seenivasan, 2012). As an alternative to the conventional treatment methods, microalgae are suggested to remove the nutrients from wastewater.

Microalgae are tiny single-celled algae that can be either eukaryotic, like green algae, or prokaryotic, like cyanobacteria. They are the primary producers in the aquatic ecosystem, with about 40,000 to 100,000 identified species documented (Jacob-Lopes et al., 2020). Microalgae are considered as living cell factories (Eltanahy & Torkey, 2021). At an efficiency rate of 10–20%, they are known to have an excellent photosynthetic ability, much higher than most terrestrial plants at 1%–2% (Singh & Ahluwalia, 2013). Hence, with their remarkable survival skills when exposed to extreme environments, microalgae have gained growing popularity for their potential in various biotechnological applications (Oco et al., 2024; Fleurence, 2021; Mohammad Mirzaie et al., 2016). Microalgal biofilms provide a sustainable alternative to conventional wastewater treatment methods such as activated sludge. In support of a circular bioeconomy, they effectively extract and recover nitrogen and phosphorus while generating biomass that may be recycled into fertiliser, biofuels, and other useful goods. Compared to sludge-based techniques, these systems produce less waste, use less energy, and rely on photosynthesis rather than aeration. Microalgal biofilms are a reliable, economical, and ecologically friendly answer to contemporary wastewater management problems since they also absorb carbon dioxide during growth and adapt effectively to a variety of wastewater streams.

The traditional approach often depends on planktonic microalgal cells that move freely in the medium. However, new advancements indicate that biofilm-based systems have notable benefits. Microalgal biofilm consists of densely packed cells, creating a structured community that sticks to surfaces, resulting in a more stable and concentrated mass. They are more robust and can withstand toxic and fluctuating environmental conditions (Kilbane, 2022). They also produce higher biomass concentrations due to reduced cultivation medium requirements than the suspended growth systems in the planktonic cells (Barros et al., 2015; Cheng et al., 2017). In addition, cells in microalgal biofilms can be easily separated from their growth medium by scraping off the surface without requiring costly separation techniques thus reducing the costs of harvesting the cells (Bakonyi et al., 2018; Orfanos & Manariotis, 2019; Mougin et al., 2025).

The stable growth of microalgal biofilm is significantly linked to the secretion of extracellular polymeric substances or EPS, which consists of polysaccharides, proteins, nucleic acids, and phospholipids (Sheng et al., 2010). EPS matrix represents about 90 % of the biofilm dry weight and protects the biofilm community from dehydration, toxic substances and other harsh environmental conditions (Cheah & Chan, 2022; Y. Hu et al., 2021). Due to its sticky nature, the EPS also aids in attaching other microorganisms, such as bacteria, cyanobacteria or fungi, which later become a diverse microbial community of the matured biofilm (Moreno Osorio et al., 2021; T. Wang et al., 2016). Microalgal biofilms provide a sustainable alternative to conventional wastewater treatment methods such as activated sludge (Serejo et al., 2019). In support of a circular bioeconomy, they effectively extract and recover nitrogen and phosphorus while generating biomass that may be recycled into fertiliser, biofuels, and other useful goods (Nagappan & Kumar, 2021; Ayub et al., 2025; Panchal et al., 2025). Compared to sludge-based techniques, these systems produce less waste, use less energy, and rely on photosynthesis rather than aeration. Microalgal biofilms are a reliable, economical, and ecologically friendly answer to contemporary wastewater management

problems since they also absorb carbon dioxide during growth and adapt effectively to a variety of wastewater streams (Abdelfattah et al., 2023).

The microalgal biotechnology industry is expanding rapidly because microalgae efficiently use sunlight, CO₂, and available nutrients through photosynthesis, leading to rapid biomass accumulation. The biomass contains crucial primary metabolites that can be processed to create valuable substances with many applications, especially in the food and feed industry (Morais Junior et al., 2020). Currently, East and Southeast Asia account for the majority of microalgae cultivation for food consumption (Çelekli et al., 2024; Ferreira de Oliveira & Bragotto, 2022). Due to the growing consumer demand for non-animal substitutes and anticipated future global food demands, microalgae are playing an increasingly important role in the food industry (Geada et al., 2021; Ayub et al., 2025). Microalgal biofilms are also known to absorb nutrients efficiently (Jacob-Lopes et al., 2020; Moreno-García et al., 2021). When cultivated in wastewater, microalgal biofilms can utilize the 'free' inorganic and organic carbon, nitrogen, phosphorus, and other trace elements for cell growth and biomass accumulation while reducing these pollutants. This dual-purpose ability of microalgal biofilms has made them a popular choice, especially in research related to environmental biotechnology (Hu et al., 2021).

This study aims to evaluate the potential of local microalgal biofilms with high-yield biomass production and simultaneously able to remove pollutants of Total Nitrogen (TN) and Total phosphorus (TP) in synthetic wastewater. This will demonstrate an alternative for integrated wastewater treatment and bioresource recovery processes. The role of local microalgal isolates in biotechnology applications, particularly wastewater remediation will be explored in this study. While indigenous isolates are still underutilised, the majority of research focusses on non-native strains that need to be adapted to local conditions. Data from this study will offer a significant information gap with the potential to demonstrate the sustainability and effectiveness of local strains for biomass production and nutrient removal, leading to environmentally friendly wastewater management.

EXPERIMENTAL

Preparation of Standard Culture Media and Synthetic Wastewater (SWW)

BG-11 medium (Phyto Technology Labs, USA) at 50X concentration was prepared and autoclaved at 15 psi, 121°C for 30 minutes and allowed to cool to room temperature. Following that, the media was supplemented with antibiotic cocktail consists of ampicillin (10 mg/ml), kanamycin (5 mg/ml), cycloheximide (5 mg/ml), nystatin (100 µg/ml), and imipenem (100 µg/ml) as proposed by Miranda et al. (2017) with some modifications.

The synthetic wastewater used in this study was prepared as follows (g L⁻¹): sodium acetate trihydrate (NaAc·3H₂O) 2.44; ammonium chloride (NH₄Cl) 0.38; dipotassium phosphate (K₂ HPO₄ · 3H₂O) 0.15; potassium dihydrogen phosphate (KH₂PO₄) 0.05; calcium chloride (CaCl₂) 0.05; magnesium sulphate heptahydrate (MgSO₄ · 7H₂O) 0.04; EDTA 0.04; sodium bicarbonate (NaHCO₃) 0.08. The wastewater was then characterized by COD 1340 mg L⁻¹; NH₄⁺ -N 93.30 mg L⁻¹; PO₄³⁻ P 30.30 mg L⁻¹, pH 7.0. The synthetic wastewater composition replicates real-world conditions, with nutrient concentrations (20–50 mg/L nitrogen and 5–15 mg/L phosphorus) and trace components mimicking those found in municipal effluents, ensuring the study's findings are realistic and replicable (Xu et al., 2016).

Sample collection and maintenance

Microalgal samples were collected from the surface of rocks in a maturation pond receiving treated wastewater and rainwater in Sungai Buloh, Selangor, Malaysia (between latitude 3°14'44.4"N and

longitude 101°28'24.3"E). The sampling site was chosen for its proximity to nutrient-rich effluents, such as municipal wastewater, ensuring the collection of microalgal species naturally adapted to high nutrient loads and local environmental conditions. The samples were carefully scraped aseptically into sterile containers, transported immediately to the laboratory and kept at -4°C.

The microalgae samples were inoculated in the prepared BG-11 medium containing an antibiotic cocktail to obtain axenic cultures by suppressing bacterial and fungal contamination, (Fernandez-Valenzuela et al., 2021). The agar plate was incubated at 25 ± 2 °C under blue-red LED lamps at 1000 – 2000 lux light intensity with a 12:12 h dark-light cycle until growth was detected (Miranda et al., 2017). The growth conditions, such as light intensity and temperature are optimised laboratory setting to improve the microalgal performance, providing a controlled baseline for assessing nutrient removal efficiency (Maltsev et al., 2021).

Individual colonies were picked up and sub-cultured at least five times to obtain homogenous cultures. The purified microalgae samples were maintained in BG-11 medium with sterilized glass coverslips (22 x 22 mm) placed at the bottom of the plates as a substrate to facilitate the attachment and immobilization of biofilm (Sunoj et al., 2021). The samples were manually shaken twice daily. Preliminary identification by morphology was performed using light microscopy OLYMPUS CH20 (Japan).

Biomass production

Each of the microalgae isolates was cultivated in a six-well plate for seven days. The initial weight was standardized at 0.15 ± 0.01 g (day 0) and grown under similar conditions previously described. At the end of the incubation period, the biomass was harvested (Qin et al., 2016) and the wet cell weight (WCW) was calculated (Renuka et al., 2013) to determine the biomass yield. This process was repeated to determine the biomass production of the microalgae at the end of 14-, 21- and 28-days incubation period (Arutselvan et al., 2021).

Pollutants Removal – TN and TP analysis

Each of the microalgae isolates was inoculated at an initial weight of 0.15 ± 0.01 g in 50 ml synthetic wastewater at room temperature for seven days (Ugya et al., 2021). A control was included without the microalgae isolates. At the end of the incubation period, the isolates were centrifuged to remove the microalgal cells. The amount of TN and TP was determined using Hach (USA) reagents of CAT No. 2672245 and 2742645 respectively according to the manufacturer's instructions. The percentage of TP and TN removal is then calculated using the following formula (Renuka et al., 2013):

$$((C_0 - C) / C_0) \times 100$$

C_0 is the initial concentration of nutrients in wastewater; C is the concentration left in wastewater after treatment.

Statistical Analysis

All the experiments were carried out in independent triplicates and the data is presented as the mean values of the replicates. The data were further analyzed using one-way analysis of variance (ANOVA). A significant difference was considered at the level of $p < 0.05$. Post-hoc tests were not performed as this study aimed to determine general trends rather than detailed group-specific differences.

RESULTS AND DISCUSSION

Presumptive Identification of the Microalgae

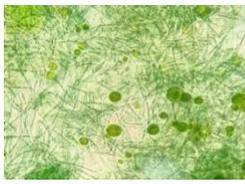
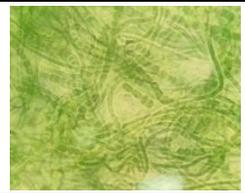
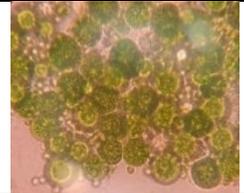
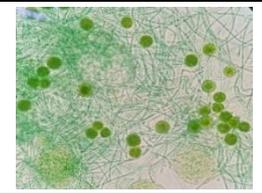
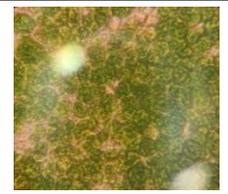
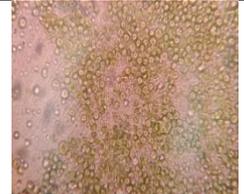
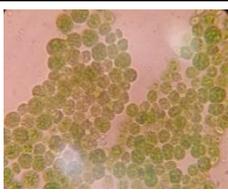
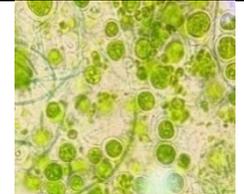
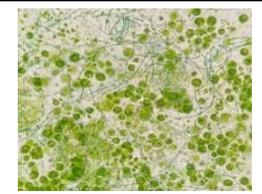
Eight microalgae were successfully isolated and preliminary identified, as shown in Table 1. The samples were divided into three groups: six were Chlorophyta, one Cyanobacteria, and one Ochrophyta. Chlorophyta, Cyanobacteria, and Ochrophyta are among the diverse microalgal species that greatly improve biofilm performance in wastewater treatment by aiding in nutrient removal and system resilience. Green algae, or chlorophyta, are renowned for their rapid growth and capacity to absorb phosphorus and nitrogen, which lowers the nutrient loads in treated wastewater (Abdelfattah et al., 2023; Shamanskyi et al., 2020). Because of their capacity to fix nitrogen, cyanobacteria enhance the nutrient pool in biofilms and encourage microbial diversity, which increases the stability and durability of biofilms (Cossey et al., 2021; Vieira et al., 2023). Ochrophyta, such as diatoms, are useful for a range of wastewater treatment situations because they support the structural integrity of biofilms and can aid in the removal of heavy metals (Plöhn et al., 2021). These strains are ecologically significant as they are naturally adapted to local wastewater conditions, ensuring efficient nutrient cycling and sustainability while minimizing the risks of introducing non-native species.

The microscopy analysis of the microalgae biofilm shows a complex structure consisting of spherical cells and filamentous strands suggesting a diversified microbial population which helps to enhance the structural stability of the biofilm (Angelaalincy et al., 2018; C. Wang et al., 2022). The symbiotic connections between the populations might boost its capacity to withstand the changing environmental circumstances and eventually contribute to the biofilm's success in sustainable applications (C. Wang et al., 2022). The interweaving of filamentous strands with spherical cells can result in increased biomass production, rendering this biofilm structure very suitable for bioresource recovery (Amorim et al., 2021; Y. Hu et al., 2021; C. Wang et al., 2022). The compact biofilm also increases the surface area used for nutrient absorption, hence improving the elimination of pollutants such as nitrogen and phosphorus in wastewater treatment (Cheah & Chan, 2022; Iasimone et al., 2021). *Chlorella* sp., *Nostoc* sp., and *Chlorococcum* sp. were reported to have biofilm-forming solid abilities due to the EPS secretions that can constitute up to 60% of the dry biomass (Chen et al., 2021; Harwati et al., 2012; Sand-Jensen, 2014). Hence, the robust biofilm formation could play a role in enhancing pollutant removal and biomass yield.

Biomass production

Over the 28-day cultivation period, the microalgae strains demonstrated significant biomass production, as shown in Figure 1. MA12, MA22, MA19 and MA4 displayed the most significant biomass yield at 90%, 76.9%, 70% and 57.1%, respectively, suggesting a good potential for application that prioritized high biomass production. Microalgae have high protein content, vital fatty acids, vitamins, and minerals. As such, the exceptional biomass output of these strains indicates their potential to be utilized to create valuable food supplements and feed additives (Zhu et al., 2023). In contrast, the other four strains exhibited comparatively low biomass production at less than 50%. These strains probably show a lower efficiency in nutrient absorption or may necessitate certain environmental conditions to achieve their maximum biomass production capacity.

Table 1. The presumptive ID for the isolated microalgae*.

Planktonic	Biofilm	Presumptive ID	Planktonic	Biofilm	Presumptive ID
		<i>Chlorosarcinopsis</i> sp. (Chlorophyta)			<i>Chlorella</i> sp. (Chlorophyta)
MA4			MA5		
		<i>Nostoc</i> sp. (Cyanobacteria)			<i>Chlorococcum</i> sp. (Chlorophyta)
MA7			MA12		
		<i>Bracteacoccus</i> sp. (Chlorophyta)			<i>Nannochloropsis</i> sp. (Ochrophyta)
MA17			MA18		
		<i>Chlorella</i> sp. (Chlorophyta)			<i>Chlorococcum</i> sp. (Chlorophyta)
MA19			MA22		

*The isolated microalgae observed under 1000X magnifications (Borowitzka, 2018; Fučíková et al., 2013; Khani-Juyabad et al., 2019; Temraleeva & Moslalenko, 2019)

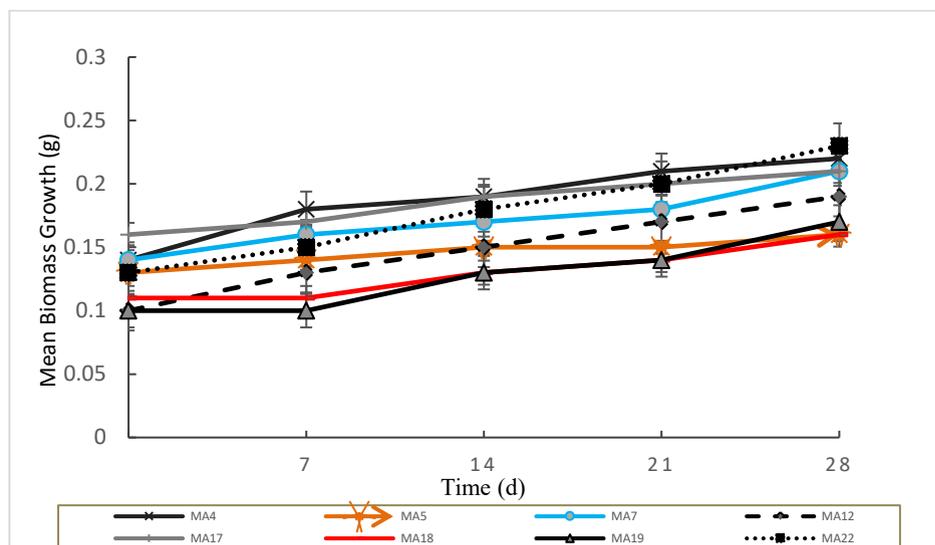


Figure 1. Biomass production rate of the isolated microalgae over 28-days period

The dominant microalgal species in MA12 was preliminarily identified as *Chlorococcum* sp., a green microalga known to be highly efficient in photosynthesis (Putri et al., 2021). *Chlorococcum* sp. also has a high capacity for lipid storage. Storing energy in the form of lipids allows it to sustain growth during periods of nutrient scarcity, further enhancing its biomass yield over time (Harwati et al., 2012). *Chlorococcum* sp. exhibits a high tolerance to environmental stress, such as high salinity or heavy metal presence (Plöhn et al., 2022; Putri et al., 2021), which can often inhibit the growth of other species (Chen et al., 2021; Harwati et al., 2012), by forming robust biofilms floating with gas bubbles (Maeda et al., 2019) and tends to form biofilm on acrylic, glass, polyurethane, and polycarbonate (Plengsakul et al., 2022). A previous study by (Shen et al., 2014) reported an excellent adhesion rate of 81.2% by *Chlorococcum* sp. which boosted the biomass productivity from 0.53 to 1.47 g. m⁻² d⁻¹ resulting in a more efficient biomass production.

High biomass-producing strains have a lot of potential for industrial-scale uses like production of biofuel or feed, especially if they have rapid growth rates and effective nutrient absorption (Chhandama et al., 2021; Panchal et al., 2025). Large-scale cultivation of these strains offers a sustainable and affordable supply of biomass for biofuels, which may replace the place of fossil fuels and lessen their negative effects on the environment (Alishah Aratboni et al., 2019). High-biomass strains can also be utilised to produce animal feed, which lessens reliance on traditional feed sources and promotes a more sustainable agricultural sector. These strains are perfect for large-scale biorefinery operations that seek to generate value-added products and renewable energy due to their scalability (Yaakob et al., 2021).

Optimisation procedures like as genetic engineering, medium changes, and light intensity control can be used to improve growth rates in strains with lower biomass production. These optimisation methods may enhance biomass production and make these strains ideal for industrial-scale applications by enhancing photosynthetic efficiency, nitrogen intake, and growing conditions (Shi et al., 2021).

The correlation between microalgae biofilm formation and biomass production is noteworthy, given that biofilms can significantly increase biomass yield (Wicker et al., 2023). Biofilms adhere to surfaces and facilitate faster development by improving microalgae's ability to absorb nutrients (Zhao et al., 2021). The biofilm structure also shields the cells from external stresses like pH variations and

temperature fluctuations, which help to promote a greater accumulation of biomass. Biofilm systems optimize space utilisation, allowing for higher cell densities and easier biomass harvesting without disturbing the culture (Patwardhan et al., 2024). Because of this, biofilms are extremely effective in biotechnology applications such as biofuel production (Miranda et al., 2017), wastewater treatment (Miranda et al., 2017; Zhao et al., 2021), and the production of food or feed (Arora Soni et al., 2016).

Microalgal Biofilms for Pollutant Removal

The capability of the isolated microalgae to remove pollutants in synthetic wastewater was further evaluated as shown in Figure 2. The structural characteristics of microalgal biofilms, including cell density and EPS synthesis, are strongly related to how effectively they remove nutrients. While EPS aids in biofilm stabilisation and microbe retention, higher cell density promotes biomass accumulation, which enhances wastewater nutrient uptake and removal (Ennaceri et al., 2023). An average ability to remove nitrogen was observed among the isolates. The highest TN removal rate was demonstrated by MA18 at 43.5 % whilst the remaining seven isolates were able to remove TN at a lower rate of between 0.3 - 31.3%. In contrast, an excellent performance of phosphorus removal among the microalgae was observed. MA7 demonstrated a remarkable capacity to eliminate 95% of the TP, nearly eliminating the entire phosphate content in the synthetic wastewater. This is followed by removal rates at 53.8% and 50.8% by MA5 and MA4 respectively, indicating successful reduction of more than half of the TP content in the wastewater. The remarkable efficiency suggests the strain's capacity to efficiently use phosphate in its metabolic activities or quickly sequester it as a molecule for storage. In contrast, an average TP removal rate was observed in the remaining microalgae strains at 25.2% - 35.3%. This lower pollutant removal efficiency could be attributed to less favorable environmental circumstances affecting the strain's activity or slower nitrogen or phosphorus absorption rate by these strains. For large-scale wastewater treatment, the differences in pollutant removal efficiency between isolates have important significance. Certain isolates may exhibit greater rates of nutrient removal than others, underscoring the necessity of meticulous strain selection and optimisation. Variability may influence the design of treatment systems for large-scale applications, necessitating the employment of strain-specific adaptations or mixed consortia to guarantee consistent performance and optimise nutrient removal efficiency under a range of wastewater conditions.

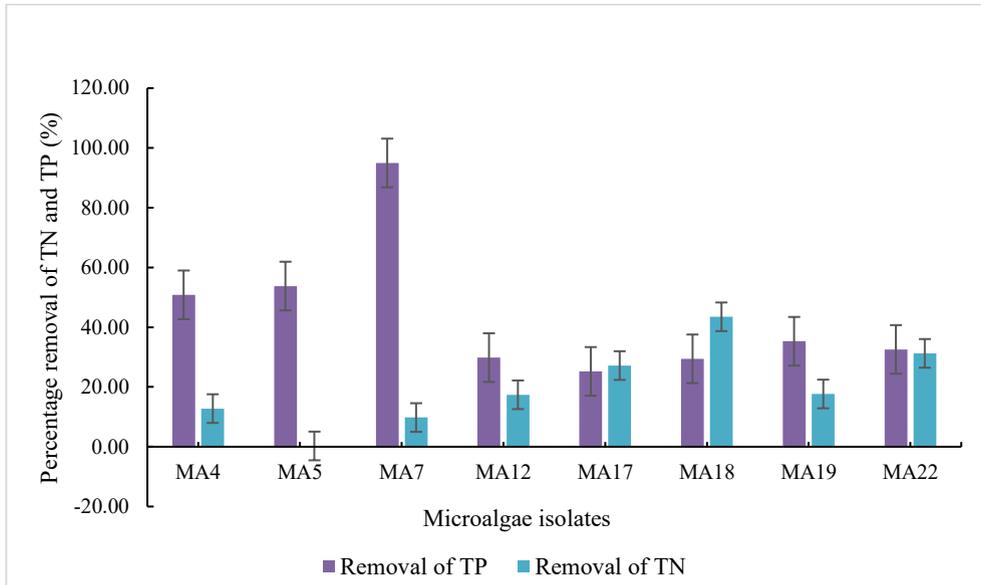


Figure 2. Removal of TP and TN by the isolated microalgae

Preliminary identification revealed that strain MA18 is most likely *Nannochloropsis*, a species known to assimilate nitrogen rapidly and incorporate it into cellular components such as proteins and nucleic acids (Simionato et al., 2013). Wastewater is typically rich in nutrients like nitrogen, and *Nannochloropsis* sp. thrives in such environments. This species can utilize various forms of nitrogen, including nitrate (NO_3^-), ammonium (NH_4^+) and even organic nitrogen compounds (H. Hu & Zhou, 2010). Previous findings demonstrated that employing *N. oceanica* resulted in a significant TN removal rate of 97.02 % under fed-batch treatment mode in wastewater (Li et al., 2024). In comparison, the removal rate by *N. oculata* was recorded at 74–90% (Şirin & Sillanpää, 2015). According to (Garbowski et al., 2020), Total Nitrogen (TN) concentrations regularly decreased due to the biofilm's development using microalgae biomass.

Subsequently, MA7 displayed an excellent ability in removing TP and is preliminarily identified as *Nostoc* sp. Phosphorus is an essential nutrient for cell development, being a key component of nucleic acids, ATP, and phospholipids. Studies have shown that cyanobacteria like *Nostoc* sp. can accumulate and store excess phosphorus during periods of abundance and use it during nutrient scarcity (Solovchenko et al., 2008). Additionally, it has been observed that the microalgae may produce robust biofilms that expand their surface area and offer a stable for nutrient absorption (Raghavan et al., 2020). The biofilm structure traps phosphorus, allowing the cells to absorb and store it more efficiently from the surrounding water. *Nostoc* sp. thrives in nutrient-rich environments such as wastewater (Riba et al., 2020).

Similarly, a study has shown that a local isolate of *Nostoc* sp. LS04 eliminated 86.05-92.22% of TP in 25-100% of wastewater (Silambarasan et al., 2021). In such conditions, phosphorus available in high concentrations can be assimilated for biomass production and metabolic processes (Riba et al., 2020). In some of the microalgae strains, low phosphorus removal efficiencies were observed. Some studies suggested this could be due to the poor microalgal biofilm structure with less dense or architecturally simple forms, as they may have less surface area for nutrient absorption (Maltsev et al., 2023). This is particularly important in wastewater treatment applications since optimizing nutrient absorption is a significant goal (Ennaceri et al., 2023). The comparatively low phosphorus removal may also indicate that other modes of nutrient removal are prioritized in situations where phosphorus is not the limiting nutrient (Abdelfattah et

al., 2023). Hence, the TN and TP removal efficiencies of local isolates in this study were comparable to or better than those reported in other studies, showing that native strains can perform well in nutrient removal. This highlights the potential of local isolates as a sustainable and cost-effective alternative to non-native species for wastewater treatment.

It is important to note that, microalgal biofilms serve a dual purpose: environment protection and aid in resource recovery. In addition to eliminating wastewater of pollutants like phosphorus and nitrogen, they also produce useful biomass that may be turned into animal feed, biofuels, and other bio-based goods (Jia & Yuan, 2016; Sengupta et al., 2015). This dual purpose improves wastewater treatment's sustainability by addressing resource usage and environmental issues. Combining biofilm reactors with conventional treatment techniques (such as activated sludge) is one way to incorporate microalgal biofilms into current wastewater treatment systems. This will enhance nutrient removal and system efficiency. Furthermore, maximising biofilm performance in wastewater treatment can be achieved by optimising biofilm development parameters, such as light and nutrition levels. Microalgal biofilms could potentially be gradually included into modular or retrofit systems, guaranteeing cost-effectiveness and causing the least amount of disturbance to ongoing operations (Gao et al., 2015; Huang et al., 2023).

CONCLUSION

The findings indicate that local microalgal biofilms have the potential to be a vital component as an eco-friendly solution in sustainable wastewater treatment by effectively removing pollutants and, simultaneously producing biomass for biotechnological applications, which provide environmental and economic benefits. This dual role promotes sustainability and the circular economy by transforming waste into valuable resources. Future studies include determining the possible symbiotic relationship between mixed biofilm consortia, such as biofilm-forming microalgae and bacteria as a consortium, as these microbes can use a wide range of different substrates in the wastewater, defining the structural pillar of the ecosystem and hence effectively contributing to wastewater treatment. It is hoped that this consortium would give a better yield in biomass production and subsequently a more efficient alternative in removing pollutant. Additionally, optimising environmental variables such as light intensity, temperature, and nutrient availability may improve the performance of these biofilms in wastewater treatment, making them more effective and adaptable to large-scale applications.

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AUTHOR'S CONTRIBUTION

Nik Airin carried out the research and draft the manuscript. Faiz conceptualised the central research idea and provided the theoretical framework. Aziyah supervised the research progress and designed the structure of the manuscript; Aziyah, Umi Marshida and Norashirene anchored the review and revised the manuscript.

CONFLICT OF INTEREST STATEMENT

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare absence of conflicting interests with the funders.

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