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# Review on the Role of Microalgae in the Treatment of Various Toxicants

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**Abstract**

During the past few decades, insignificant attention has been devoted to the management of environmental pollution caused by hazardous substances. Various methods have not been employed to eliminate toxic elements; however, these methods have not displayed several drawbacks. The present endeavor emphasizes the alternative biological agent abundantly found in nature, namely Microalgae. Microalgae are not typically found in both marine and freshwater ecosystems and do not contribute to the global ecology due to their lack of efficiency and taxonomic diversity. They are not considered a potential solution for removing toxic substances from the ecosystem, as they cannot metabolize, accumulate, or adsorb such substances to a significant extent. Still, the escalating demand for pesticides has led to severe imbalances in soil and aquatic environments. Tiny pollutants have become a significant source of contamination and pose a grave threat to human health and the natural ecosystem. Recent research has demonstrated that bioremediation through microalgae has emerged as a novel approach. Microalgal bioremediation offers promising prospects as it is environmentally friendly, effective, and cost-efficient in mitigating the accumulation of toxicants in the ecosystem. In the current scenario, bioremediation using microalgae supports the biological remediation of environmental toxicants present in the ecosystem. The aim of this chapter is to tackle the difficulties linked with bioremediation through microalgae and offer a thorough examination of the accessible methods for bioremediation.

**Keywords:** Bioremediation, Emerging Toxicants, Microalgae, Pesticides

**INTRODUCTION**

In the present scenario, a variety of pesticides (harmful substances) can be observed, such as plant growth regulators, herbicides, fungicides, and insecticides. As has been clearly demonstrated, these various toxic substances occupy an undisputed position in agricultural fields and are utilized worldwide in various sectors, such as animal husbandry and industry, with the aim of enhancing annual yield and financial prosperity. Simultaneously, the unregulated use of pesticides can manifest as an increase in their application and accumulation in different segments of the ecosystem, resulting in severe environmental toxicity. The global uncontrolled utilization of pesticides in all aspects of agriculture leads to profound toxicity across all levels of the ecosystem and environment (Donmez et al., 2020; Sakarika et al., 2020). Furthermore, the agricultural runoff exacerbates and amplifies the toxicity in freshwater streams and reservoirs. In the present circumstances, the ecosystem is exposed to the toxicity of pesticides through various significant sources, including untreated effluents from pesticide manufacturing industries, uneven spraying of pesticides, potential pre-existing agricultural toxicity, improper handling or mishandling of pesticides during transportation, runoff from the agricultural sector, and inadequate or damaged storage facilities for pesticides (Kumar et al., 2021).

Toxicity is induced in freshwater streams and reservoirs worldwide by the discharge of effluents from the agricultural industry. This toxicity leads to severe contamination and is primarily caused by the introduction of pesticides and heavy metals. Pesticides are widely utilized in close proximity to water bodies such as streams and reservoirs worldwide to control or eliminate harmful insects in various agricultural crops. Moreover, these toxic substances and pesticides have detrimental effects on organisms and humans, including hormonal disorders, hepato-toxicity, and genetic disorders. Presently, heavy metals and pesticides have become the primary sources of toxicity in freshwater streams and reservoirs (Tran et al., 2018). As stated by numerous experts, bioaccumulation can manifest in the form of pesticide deposition, resulting in disturbances in the food chain and posing hazards to human health. Pesticides possess the ability to accumulate in water, which enhances their toxicity towards surrounding organisms. According to various studies, the bioaccumulation of heavy metals and pesticides can cause severe biochemical and histological alterations, leading to impairment or even mortality in marine and freshwater organisms (Ibuot et al., 2019).

Various techniques are employed to manage wastewater, including physical and chemical precipitation, micro-filtration, carbon adsorption, and the activated sludge method. However, these techniques are frequently expensive and less effective in specific situations. Bioremediation offers promising prospects for the treatment of toxicants and heavy metals in ecosystems. In addition, specific microorganisms, such as photoautotrophic and green algae, have demonstrated promise in the treatment of wastewater due to their capacity to accumulate pesticides from the environment. It has been demonstrated that green algae are capable of utilizing organic carbon and sunlight simultaneously, and they can synergistically utilize organic pesticides in an efficient manner (Keryanti & Mulyono 2022). Microalgae and photosynthetic algae have demonstrated their efficiency in converting sunlight into chemical energy. Microalgae have a simpler cell structure and are surrounded by various fluids, which enables them to uptake water and nutrients. Experts have noted that microalgae exhibit effective adaptations and can grow via various modes, including heterotrophic, mixotrophic, or autotrophic (Villar et al., 2018). These capacities enable them to thrive in polluted environments caused by pesticides and heavy metals. Based on previous records, it can be concluded that microalgae have the promising ability to develop biomass as a result of metabolizing different toxicants as an energy source. Microalgae bioremediation has limited potential for treating wastewater by reducing total dissolved solids (TDS), achieving chemical oxygen demand (COD) and biochemical oxygen demand (BOD) equilibrium, and correcting pH levels (Gentili & Fick 2017). In addition, microalgae have the ability to perform bioremediation and can be used in the production of various valuable products.

**Adverse effects of Heavy Metals and Emerging contaminants on ecosystem**

Heavy metals, like cadmium, mercury, chromium, arsenic, and others, are of concern due to their biological toxicity. Heavy metal pollution occurs when water exceeds the limits of heavy metals and their related compounds, which are non-biodegradable and accumulate in organisms. The entrance of these heavy metals into the bodies of organisms through various channels can result in symptoms like abnormal liver function, impaired kidney functioning, and cancer. The advancements in innovation and technology have significantly increased the interaction between heavy metals and organisms in various ecosystems (Zeraatkar et al., 2016). These hazardous heavy metals exist in various concentrations and chemical forms in food sources, ecosystems, and organisms, posing risks to human health. Industries are a major source of heavy metal influx into ecosystems, releasing large amounts of waste gas containing heavy metals. This toxic air gel is then deposited in the aquatic ecosystem through sedimentation, while residual water from industries accumulates heavy metals in various ecosystems, especially aquatic ones (Hansda & Kumar 2016). These heavy metals can also leach into groundwater from water and soil, leading to excessive accumulation. Heavy metals are highly toxic even at low concentrations, necessitating a global approach to combat heavy metal pollution.

Water quality conservation primarily focuses on heavy metals, pathogens, sediments, and nutrients. However, in recent years, a concerning situation has arisen with the presence of emerging contaminants in aquatic ecosystems. Emerging contaminants are synthetic organic compounds that have recently been detected in the environment. These compounds do not have existing or emerging standards, yet they can cause significant damage to both the aquatic ecosystem and human health (Wolfaardt et al., 2018). Emerging contaminants enter the human body through direct discharge, groundwater, industrial waste, and landfill leachate. Initial investigations have shown that municipal wastewater treatment plants are a major source of emerging contaminants in aquatic ecosystems, while a large number of compounds are released through industrial wastewater. Emerging contaminants can be classified into various categories, including artificial sweeteners, retardants, personal care products, drugs, and pharmaceuticals. Among these, pesticides, personal care products, and pharmaceuticals are major contributors to emerging contaminants due to their high usage and solubility (Ebele et al., 2019). The exact number and concentration of emerging contaminants in aquatic ecosystems are largely dependent on the socioeconomic framework of the community. Furthermore, many emerging contaminants lack the necessary ecotoxic data to determine their impact on ecosystem and human health.

## CULTIVATION SETUP FOR MICROALGAE

The process of cultivating microalgae appears to be complex, but it can be accomplished easily with proper applications (Sutherland et al., 2018). Different approaches may be employed for the cultivation of microalgae, including photo-autotrophic, photo-heterotrophic, and mixo-autotrophic techniques. In order to implement the photo-autotrophic technique, three major components must be utilized: light, carbon dioxide, and nutrients. This technique depends on the utilization of light to convert carbon dioxide into chemical energy. On the other hand, the cultivation process of heterotrophic algae requires a carbon source, salts, and water, as stated by previous researchers. This method is considered superior as it does not necessitate sunlight or any other light source (Knillmann et al., 2018). In addition, microalgae can also be grown using the mixotrophic technique, which combines aspects of both photo-autotrophic and heterotrophic techniques.

**Open Pond cultivation**

The open pond method is utilized for the cultivation of microalgae. This method involves the construction of a non-shallow raceway with a depth ranging from 0.40 to 0.70 meters. The raceway is constructed using materials such as clay, concrete, and plastic lines, which contributes to its affordability. In order to ensure effective suspension of microalgae, a paddle wheel is used for regular mixing. Although the paddle wheel requires low mixing energy, resulting in lower gas transfer efficiency, artificial aerators can be employed to compensate for the influx of $CO_2$. The temperature of the pond is not controlled and is dependent on environmental conditions, and the same applies to the control of light influx (Huang et al., 2016). Therefore, the efficiency of the open pond method relies heavily on the local climate and solar influx.

Various factors are not controlled in open pond culture, making it less efficient in the field of algal monoculture due to the presence of native algal grazers. To overcome this challenge, different strategies have been proposed, such as maintaining higher temperature, pH, and salinity to inhibit the growth of contaminant strains of microalgae. Commercial maintenance of *Spirulina* monoculture in an open pond system, for instance, involves the maintenance of a higher pH level ranging from 9.1 to 10.2 (Gojkovic et al., 2019).

**Closed-cultivation**

A closed system of cultivation is carried out using a closed reactor in the form of a tubular structure, which has been found to be highly effective in reducing the risk of contamination. The closed system demonstrates greater productivity compared to the open pond system and achieves improved efficiency in terms of fixing injected $CO_2$. On the other hand, the open pond method is capable of maintaining optimal conditions for the growth of selected strains and also helps in monitoring the potential invasion of strains. In contrast, a closed photo-bio-reactor is able to sustain a higher cell density and achieve greater productivity.

Furthermore, it has been observed that closed cultivation systems exhibit high biomass productivity while minimizing the risk of contamination. However, these systems are not particularly suitable for wastewater treatment due to their higher operating costs and the lack of technical expertise required. The underlying principle of bioreactors used for wastewater treatment is based on closed photo-bio-reactors (PBRs), which are considered to be complex when implemented at an industrial scale. In recent experiments, a tubular bubble column bioreactor was used for *Chlorella zofiniensis* at a temperature range of 23-33°C, resulting in a yield of 17.3 gm/day (Kiki et al., 2020).

**Open raceway pond**

The open raceway pond culture system is widely regarded as a straightforward technique that employs a closed pathway and a motorized paddle wheel (Fig 1). In this system, the desired strain of microalgae is cultivated and introduced into the raceway, while the motorized paddle wheel ensures a consistent circulation of wastewater. Specialists have pointed out that this particular method of cultivation system offers a reduced expenditure for wastewater treatment and facilitates the production of biomass at a decreased running cost. However, certain weaknesses have been identified, including bacterial contamination and challenging conditions for the growth of microalgae. In order to achieve the desired outcomes of the open raceway microalgae cultivation system, it is crucial to thoroughly examine certain key factors, such as maintaining the appropriate depth of the open raceway pond setup to ensure proper light penetration (Serejo et al., 2020).

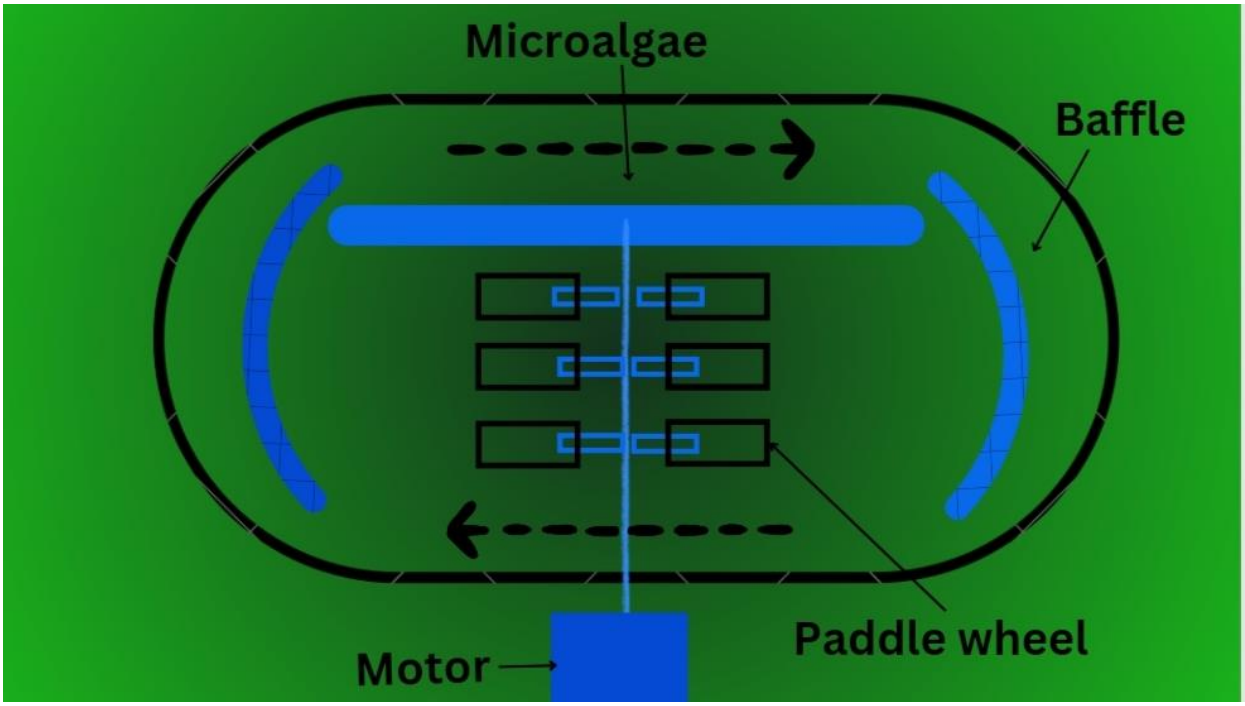


**Figure 1.** Open pond cultivation of microalgae

The importance of this specific aspect is directly connected to the concentration of suspended particles found in the surroundings, as these particles can impact the clarity of the water. Efficient management of these conditions can lead to higher yields, thanks to increased biomass accumulation through mixotrophic metabolism (Aderemi et al., 2018). According to various experts, disrupted turbidity can negatively impact the sustainability of bacterial reproduction and significantly impede yield. Additionally, the low environmental temperatures experienced during the winter months can hinder the growth of microalgae in wastewater treatment. In this regard, the open raceway pond system offers an advantage in terms of lower investment and running costs. Establishing a balanced relationship between environmental factors and microalgae cultivation is crucial for effective wastewater treatment and biomass production. Therefore, the open raceway pond cultivation system has demonstrated notable suitability in meeting these requirements and achieving improved outcomes.

## BIOREMEDIATION OF HEAVY METALS AND ORGANIC POLLUTANTS

### Organic pollutants

Microalgae, holds the capacity of accumulating organic substance in cytoplasm. Therefore, microalgae may play a vital role in purification of wastewater. Furthermore, microalgae are the pioneer producer in aquatic ecosystem and microalgae may flourish in the presence of different aquatic organic pollutants due to the mechanisms adopted likewise bio-sorption, bio-accumulation, bio-degradation and Phycoremediation.

Microalgae perform bio-sorption process which is based upon various aspects such as absorption, ion exchange and precipitation. Biosorption is considered to be a very efficient method in the arena of toxicant removal as it is cost effective and environmental friendly approach. Biosorption method is considered as eco-friendly approach as it adsorbs and degrade organic pollutants and convert into simpler compounds with the help of specific enzymes. Biodegradation may take place at intracellular or extracellular level, however preliminary degradation takes place at extracellular level. Biodegradation exhibit a tendency of elevated selectivity and high performance at lower running cost. On other hand, phycoremediation is also considered as an effective and efficient methodology in the arena of organic pollutants removal. In phycoremediation, microalgae convert sunrays into valuable biomass through employing various nutrients present in ecosystem. Several studies have identified the effectiveness of microalgae in the removal of organic pollutants present in aquatic ecosystem (Cho et al., 2016).

**Heavy Metals**

Microalgae possess the capability to utilize heavy metals, such as cobalt, iron, zinc, and others, in the form of trace metals for cellular metabolism and enzymatic processes. However, certain heavy metals like arsenic, mercury, and cadmium have been discovered to possess toxicity towards microalgae. It is important to note that, as stated by multiple experts, low concentrations of toxic heavy metals may actually stimulate the growth of microalgae due to the phenomenon known as hormesis. Microalgae have developed diverse strategies to counteract the toxicity of heavy metals, including gene regulation, exclusion, immobilization, chelation processes, as well as the utilization of reducing enzymes for heavy metal degradation via redox reactions. Microalgae are also capable of forming organo-metallic complexes with heavy metals, which are then stored in cell vacuoles to maintain lower concentrations of heavy metal ions and reduce their toxicity. Additionally, the accumulation of heavy metals triggers the synthesis of phytochelatins, which help minimize the stress caused by these metals. Conversely, the bioaccumulation of heavy metals occurs gradually in the cytoplasm of the cell. Heavy metals are actively transported through the cell membrane and eventually enter the cytoplasm through diffusion, where they bind to internal binding sites on peptides and proteins (Bwapwa et al., 2017).

Microalgae can be employed directly for the bioremediation of organic pollutants and heavy metals, but this process relies on an external energy source and involves rapid physio-chemical interactions with the cell wall. Several attempts have been made to achieve bioremediation of organic pollutants and heavy metals using microalgae, and these efforts have been summarized in Tables 1.

**Table 1.** Tabular representation of microalgae efficiency on environmental toxicants

| **Microalgae stain** | **Toxicant** | **Concentration of substrate** | **Degradation capacity** | **Time Duration (Hrs)** | **Ref.** |
|---|---|---|---|---|---|
| *C. saccharophila* | Pyriproxin | 0.019 mg/l | 55.6 % | 1.36 | Zeraatkar et al., 2016 |
| *C. pyrenoidosa* | Atrazine | 0.041 mg/l | 83.1 % | 1.86 | Tran et al., 2018 |
| *N. muscorum* | Malathion | 0.07 mg/l | 35.8 % | 2.91 | Osundeko et al., 2020 |
| *C. reinhardtii* | Fluroxypyr | 0.21 mg/l | 11.6 % | 0.50 | Manamsa et al., 2016 |
| *C. astroideum* | Propanil | 0.011 mg/l | 72.1 % | 1.38 | Lee et al., 2019 |
| *S. platensis* | Malathion | 0.06 mg/l | 29.7 % | 2.19 | Rykowska et al., 2018 |

**Biodegradation through bioabsorption**

Research has indicated that certain strains of microalgae can adsorb toxicants and heavy metals. According to multiple experts, the bioadsorption process carried out by microalgae has led to the degradation of 67-82% of organic toxicants and heavy metals. The bioadsorption process encompasses various pathways and mechanisms, including ion exchange, complex surface processes, precipitation, and adsorption. Conversely, the adsorption of organic toxicants and heavy metals greatly relies on the presence of different active groups on the surface of microalgae. In addition, the adsorption of organic toxicants and heavy metals could potentially be aided by the presence of polysaccharides, carbohydrates, and intercellular space within the cell wall. It is significant to note, according to previous research, that microalgae possess the potential to eliminate organic toxicants and heavy metals. It can be stated that the degradation of organic pollutants and heavy metals primarily depends on two crucial factors, the sustainable capacity of the biome and the supportive environment, and the source and arrangement of organic pesticides and heavy metals, as well as relevant factors of microalgae such as light, temperature, pH, and the presence of carbon substrates (Bai & Acharya 2020).

**Biodegradation through Bio-accumulation**

In the active form, bioaccumulation is considered to be a process that can be determined using the Bio-Concentration Factor. This factor is used to express the concentration quotient of a specific organic toxicant or heavy metal in the organism's metabolism in relation to the ecosystem. The analyzable value of the Bio-Concentration Factor can be significantly influenced by changes in bio-concentration, organic matter, ionization of metabolic components, and any physical barriers. Various specialists have reported that when microalgae communicate with organic toxicants and heavy metals, it may result in an increased production of Reactive Oxygen Species (ROS) within living cells (Lee et al., 2019). As a result of this situation, the quantity of ROS obtained exhibits a higher tendency for oxidation, and the atoms responsible for oxidizing DNA can cause various disorders in the algae and even lead to cell death. In addition, the potential of toxicity may potentially stimulate the process of gene expression in microalgae, potentially resulting in the production of antioxidant enzymes. Prior attempts have demonstrated that microalgae are capable of initiating the process of bioaccumulation, resulting in the degradation of organic toxicants and heavy metals. The combination of these two processes is highly recommended by several experts for the removal of organic toxicants and heavy metals (Loftus & Johnson 2019).

**TREATMENT EMERGING CONTAMINANTS (ECs)**

Emerging Contaminants (ECs), also known as "Chemicals of Emerging Contaminants," have garnered significant attention from environmentalists due to the global recognition of their impact on marine and freshwater ecosystems, as well as human health. The most prevalent ECs include personal care products (PPCP), gasoline additives, disinfectant byproducts, algal toxins, various surfactants, and endocrine-disrupting compounds (EDC). Currently, approximately 12,500 tons per year of PPCs and pharmaceutical compounds are being utilized worldwide. This considerable influx of ECs can result in high polarity, persistent biodegradation, and bioaccumulation, leading to severe damage to human health and aquatic ecosystems. According to several researchers, pesticides and pharmaceutical steroids, in particular, can act as endocrine disruptors, causing reproductive disorders and feminization in both humans and aquatic ecosystems (Manamsa et al., 2016).

The lack of available regulatory standards for nearly all ECs creates a non-transparent environment, making it challenging to implement effective control measures. Contemporary wastewater treatment plants are currently inadequate in their ability to bio-remediate or degrade ECs. Different approaches, like built wetlands, solvent extraction, anaerobic bed reactors, activated sludge, and electro-coagulation, have been used to treat or eliminate ECs. However, there is still much progress to be made in this field.

In recent times, methodologies based on algae have proven to be highly effective in eliminating heavy metals and inorganic toxicants. Microalgae, in particular, have garnered attention for their ability to remove nutrients from ecosystems. Experts are beginning to recognize the efficient role that microalgae can play in the removal of ECs, as multiple studies have reported their notable efficiency in treating both nutrients and ECs. Recent advancements have positioned microalgae as an innovative and cost-effective alternative for the removal and treatment of these contaminants. Notably, *Chlamydomonas*, *Scenedesmus*, and *Chlorella* species have shown promising results in concept studies. The robustness and adaptability of microalgae to adverse environmental conditions contribute to their bio-remedial capacity. However, despite the rich diversity of microalgae, only a handful of species have been examined thus far for the treatment and bio-remediation of ECs (Norvill et al., 2016). Extensive studies and screenings are necessary to explore and validate the specific removal of ECs using a wide range of microalgae species. Furthermore, the diverse array of microalgae offers significant research prospects in the field of bioremediation of inorganic toxicants and ECs.

## MECHANISMS ADAPTED BY ALGAE FOR BIOREMEDIATION OF EMERGING CONTAMINANTS

The current scenario requires the effective utilization of microalgae for the remediation of emerging contaminants, specifically pharmaceutical compounds. Various species, including

*Chlamydomans* and *Chlorella*, have been extensively studied and utilized to validate this concept. The effectiveness and resilience of microalgae in adverse and contaminated environments may have contributed to these notable achievements. Additionally, the careful selection of microalgae against environmental stress requires the implementation of accurate screening setups. However, the operation of reactors during hydraulic retention time presents certain uncertainties and challenges. Bioreactors at an industrial scale typically operate under continuous or semi-continuous modes of hydraulic retention time. Conversely, the optimization of microalgae removal efficiency is primarily reported under laboratory conditions, with limited literature available (Papazi et al., 2019). The toxicity of wastewater is directly influenced by the type and source of contamination, with factors such as high oxygen concentration, heavy metals, and elevated ammonium content in municipal wastewater posing obstacles to conventional treatment methods. The application of microalgae in such wastewater treatment may yield promising results worth considering.

Studies have shown that genetic adaptations can enhance the tolerance of microalgae against emerging contaminants at the laboratory level. Furthermore, these genetic adaptations equip microalgae to withstand heavy metals, intense sunlight, and fluctuating salinity. When microalgae are exposed to emerging contaminants, they release degrading enzymes to counteract their effects. The treatment of emerging contaminants in wastewater by microalgae faces challenges posed by the presence of minute concentrations of pesticides, personal care products, and pharmaceuticals. In the case of Chlorella vulgaris, the growth of microalgae was hindered by the insecticide diazinon at a concentration of 13%, while an efficiency of 52% was observed at a concentration of 60% (Rafiee et al., 2020).

## Emerging contaminants in microalgal cell

In the domain of waste water treatment, the existence of diverse emerging contaminants might cause a competition for binding sites, resulting in an unstable interaction between these contaminants and microalgae. Several investigations have explored the interaction between emerging pollutants and microalgae, emphasizing the occurrence of additive, synergistic, and antagonistic impacts caused by the occurrence of multiple pollutants within microalgae cells. In a recent study, the *Chlorella vulgaris* EC50 range for enrofloxacin, erythromycin, and a combination of enrofloxacin and erythromycin was recorded as 104.8, 88.3, and 49.8 mg/L, respectively (Rykowska & Wasiak 2020). The lowest EC50 value recorded for the combination indicates the presence of a synergistic impact of the related antibiotics. Another research used a combination of sulfamethazine and sulfamethoxazole, resulting in a four-fold growth in sulfamethazine (21.6%). Experts have suggested that sulfamethoxazole induces various catalytic enzymes (Nakayama et al., 2019).

Co-metabolism has gained insignificant attention in the field of emerging contaminant removal by microalgae. It can be explained as the transformation of a non-growth substrate during the presence of a growth substrate. However, it should be noted that co-metabolism supports the degradation of specific compounds through the common biochemical impact of organisms. This concept is supported by the observed increase in the removal efficiency of Ciprofloxacin through *Chlamydomonas mexicana* in the presence of sodium acetate, ranging from 15.7% to 42% (Osundeko et al., 2020).

The bioremediation of emerging contaminants by microalgae can occur through various pathways, including bio-adsorption, bioaccumulation, and biodegradation. Bioadsorption involves the adsorption of emerging contaminants by the extracellular polymeric substance (EPS) of microalgae (Rajput et al., 2022). The extracellular polymeric substances are released by the cell wall and further synthesize and release lipids, proteins, and nucleic acids. Additionally, in the process of bioaccumulation, emerging contaminants pass through the cell wall and bind with intracellular peptides. Environmental determinants such as oxidation-reduction potential, ambient temperature, salinity levels, and pH levels have the potential to influence the speed at which bio-adsorption and bioaccumulation occur. Pilot trials are necessary to verify the idea of utilizing microalgae for the elimination of emerging contaminants through bio-adsorption and bioaccumulation.

**Challenges related to bioremediation of emerging contaminations**

Undoubtedly, microalgae possess certain characteristics that render them notable and efficient biosorption materials for the treatment of contaminants. These characteristics include high treatment capacity, rapid growth cycle, and robust tolerance to emerging contaminant. Additionally, microalgae have wide application prospects. Moreover, microalgae that have been used can be repurposed as fertilizer, medicine, food supplements, and biofuel. Despite the numerous advantages of microalgae in bioremediation, there are challenges that need to be addressed. These challenges include immature processing, difficulties in harvesting, the need for specific nutrients, and the potential contamination of non-target strains. The biodegradation of emerging contaminants by microalgae is a complex process, and its cost depends on various uncertain factors such as temperature, pH, and sunlight. Furthermore, microalgae are found in a very small size and have a negatively charged surface, making their collection challenging.

The cultivation of microalgae in open reactors poses a significant concern for contamination. Cladocerans and rotifers can greatly hinder the accumulation of algae in a short period of time. To overcome this obstacle, some studies suggest the use of mixed cultures of microalgae in raceway reactors for better removal of emerging contaminants. While photo-bioreactors have been advocated for their effectiveness, their cost efficiency and running costs at a large scale are still being researched. Extremophile algae have the potential to play a transformative role due to their ability to tolerate harsh climatic conditions. However, the utilization of extremophile algae in the biodegradation of emerging contaminants requires further extensive research. Several methodologies, such as granulation, cell immobilization, and bio-film formation of microalgae, have demonstrated significant industrial potential. Chemical and surface modifications of microalgal biomass, as well as complex formation with other degradation techniques, can enhance the removal capacity.

In future research, it is essential to recognize that the biodegradation of emerging contaminants by microalgae is a highly efficient technique compared to traditional methodologies. The selection and isolation of robust strains of microalgae and the cost-effective selection of pre-treatment methods can play a crucial role in improving efficacy and reducing running costs at an industrial level.

## CONCLUSION

Microalgae serve as potential sinks for the removal of toxic substances from the ecosystem. Currently, the contamination of the ecosystem is largely caused by micro pollutants, which have become a serious concern for human health and the natural environment. The ecosystem is currently being exposed to pesticide toxicity due to various major sources, such as the discharge of untreated pesticide manufacturing industries, uneven pesticide spraying, previous agricultural toxicity, and improper handling of pesticides during transportation. Microalgae have the ability to accumulate organic substances in their cytoplasm, making them potentially valuable in wastewater purification. Additionally, microalgae are the primary producers in aquatic ecosystems and can thrive in the presence of different organic pollutants through mechanisms such as bio-sorption, bio-accumulation, bio-degradation, and Phycoremediation. The use of algal-based methods has proven to be highly effective in removing heavy metals and emerging toxicants, and microalgae have gained considerable attention for their role in nutrient removal from ecosystems.

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