Algae: The green solution for basic sanitation

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Keyla Nunes Farias Gomes[1], Julianne Soares Pereira[2], Geovana Espíndola Jardim[3], Patrícia Soares Santiago[4], Leandro Rocha[5] and Robson Xavier Faria[6]

ABSTRACT

The use of algae in basic sanitation and water purification is a promising approach. Algae, both microalgae and macroalgae, are photosynthetic organisms that play a crucial role in removing nutrients and contaminants from effluents. They have been extensively studied and applied in water and wastewater treatment systems due to their effective and sustainable ability to absorb nutrients such as nitrogen, phosphorus, and organic pollutants. Compared to conventional methods, algae-based technologies offer significant environmental benefits, including lower energy consumption and reduced reliance on chemicals. Successful examples worldwide, such as in Qingdao (China) and San Francisco (USA), demonstrate successful implementation cases, resulting in improved water quality, the promotion of sustainability, and the protection of aquatic ecosystems. In the future, it is essential to continue investing in research and development to optimize these technologies and promote their global implementation, aiming to address global challenges related to freshwater scarcity and water pollution.

Keywords: Natural filtration, Water sustainability, Water treatment, Environment, Public health.

[1] Federal University of Rio de Janeiro - Graduate Program in Plant Biotechnology and Bioprocesses, Health Sciences Center.
Environmental Health Assessment and Promotion Laboratory, Oswaldo Cruz Institute.
Natural Products Technology Laboratory, Fluminense Federal University.
[2] Fluminense Federal University - Postgraduate Program in Sciences and Biotechnology, Niterói, RJ, Brazil.
Environmental Health Assessment and Promotion Laboratory, Oswaldo Cruz Institute.
Biomolecules Laboratory, Vale da Ribeira School of Agricultural Sciences/UNESP, Campus Registro, São Paulo, Brazil.
Natural Products Technology Laboratory, Fluminense Federal University.
[3] Environmental Health Assessment and Promotion Laboratory, Oswaldo Cruz Institute.
[4] Biomolecules Laboratory, Vale da Ribeira School of Agricultural Sciences/UNESP, Campus Registro, São Paulo, Brazil.
[5] Federal University of Rio de Janeiro - Graduate Program in Plant Biotechnology and Bioprocesses, Health Sciences Center.
Natural Products Technology Laboratory, Fluminense Federal University.
[6] Fluminense Federal University - Postgraduate Program in Sciences and Biotechnology, Niterói, RJ, Brazil.
Environmental Health Assessment and Promotion Laboratory, Oswaldo Cruz Institute.

INTRODUCTION

INTRODUCTION TO ALGAE AND THEIR ENVIRONMENTAL IMPORTANCE

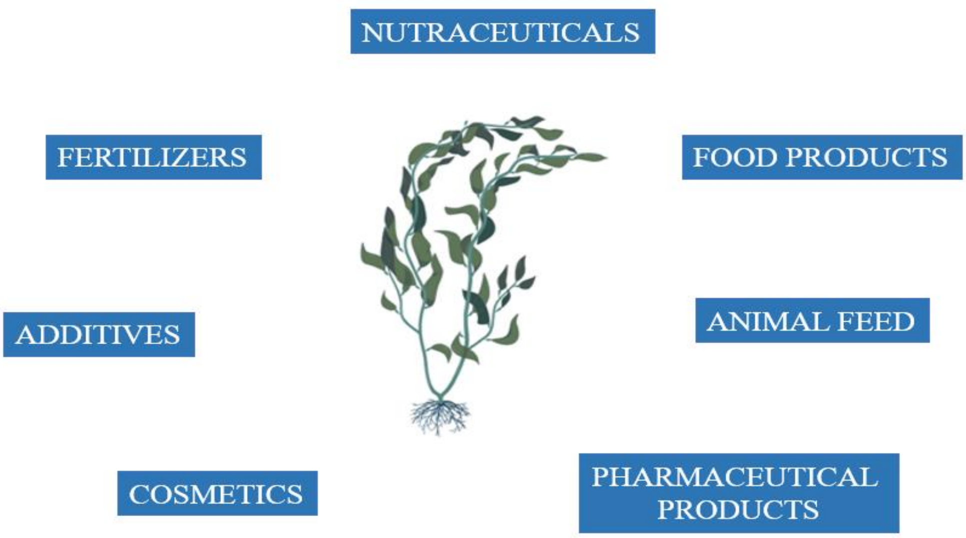
Algae are photosynthetic, eukaryotic aquatic organisms that can be unicellular or multicellular and can be identified based on color, shape, and life cycle (Chaudhary, 2020). These organisms are the primary producers of biomass in marine environments and possess various bioactive substances that can be used for human and animal health (Pereira and Faria, 2023; Pereira et al., 2023).

They can be classified into macroalgae and microalgae. Macroalgae are large photosynthetic plants that can be observed without a microscope. Microalgae are microscopic and have a significant impact on and are important for their applications. Algae are classified based on the release of their pigmentation into brown (phaeophytes), green (chlorophytes), and red (rhodophytes) categories (Chaudhary, 2020; Lee and Ryu, 2021; Pereira et al., 2023).

Algae play an essential role in the environment. These organisms contribute in various ways, primarily through nutrient absorption, coastal defense against hazardous waves, and carbon reduction in the environment (Araújo et al., 2021).

Algae are currently being utilized in various commercial sectors. They are widely established in Asia as food and supplements due to their nutritional and therapeutic properties. They are also used in the pharmaceutical, biomedical, and biotechnological industries. Other applications include livestock feed supplements, fertilizers, biostimulants for plants, and bioproducts in the cosmetics industry (Figure 1) (Araújo et al., 2021).

Figure 1: Applications of algae in various commercial and industrial sectors.



Source: Image created using the Biorender application.

BASIC SANITATION CHALLENGES

Water is an essential resource for supporting a healthy life. Its importance transcends its fundamental role as a raw material in several industries, including pharmaceutical, petrochemical, food, agrochemical, oil and gas industries, in addition to playing a crucial role in agriculture and domestic uses (Abdelfattah et al., 2023; Rashid et al., 2021).

Increased water consumption inevitably results in greater volumes of wastewater effluents. Although more than 70% of the Earth's surface is covered by water, only 3% is potable for human consumption, while the remaining 97% is salt water. Approximately four billion people globally face water shortages for at least one month each year (Rashid et al., 2021).

The direct disposal of contaminated water from these applications represents severe environmental risks and is a growing concern due to the diversity of contaminants present. There are different sources of water pollution, such as sewage, pesticides, industrial waste, and agricultural waste (Abdelfattah et al., 2023).

In addition to the environmental impacts caused by inadequate disposal, the lack of basic sanitation causes significant problems in several socioeconomic sectors, especially in health areas. Diseases transmitted by effluent waste affect both the directly exposed population and those indirectly impacted. Therefore, awareness and the implementation of preventive measures, such as adequate sewage treatment, are essential to promote healthier and more sustainable living conditions (Almeida et al., 2020; Costa et al., 2022).

In Brazil, the predominant system is the sewage network, which is the most suitable option. However, other realities include the use of rudimentary and septic tanks and direct dumping into rivers, streams, and springs, which contaminate soil and groundwater, which are vital sources for human life. Therefore, it is crucial to study the construction of sewage treatment plants, aiming to achieve a more adequate level of disposal of this waste into the environment at a more affordable cost, which can positively impact citizens' quality of life. Basic sanitation is fundamental to human well-being, as it controls public health by eliminating health risk factors and promoting social and environmental conditions that are conducive to good survival (Costa et al., 2022).

POTENTIAL OF ALGAE IN WATER PURIFICATION

Several technologies, including biological, physical, and chemical methods, have been applied to remove contaminants in aquatic environments. Advanced technologies include adsorption, chlorination, activated carbon filtration, membrane processes, advanced oxidation, photocatalysis, and the use of nanomaterials. However, these methods have significant limitations, such as high costs associated with the choice of adsorbent, expensive chemical reagents, and the potential generation of secondary pollutants in the processes (Li et al., 2021; Li et al., 2022).

Biological treatments offer distinct benefits compared to physical and chemical methods and are more environmentally sustainable and economically viable (Rambabu et al., 2020). Algae, for example, are known for their remediation capabilities in aquatic ecosystems due to their rapid growth cycle, sensitivity to pollutants, and stress response mechanisms (Li et al., 2022).

Algal-based remediation techniques have been explored since the 1950s to remove nutrients and dissolved carbon from sewage, especially because of their efficiency without additional energy demand for pollutant removal (Li et al., 2022 part 1), unlike conventional approaches such as microfiltration and sludge activation, which require high energy consumption (Li et al., 2022). Furthermore, microalgae-based technology has successfully removed up to 65% of organic microcontaminants, such as pesticides and antibiotics, from groundwater (Ferrando and Matamoros, 2020). The main removal pathways in algae have been identified, including bioadsorption, biodegradation, bioaccumulation, photodegradation, volatilization, and hydrolysis.

Bioadsorption is a physicochemical process in which biological materials, such as algal cell walls or extracellular polymeric substances (EPSs), are used to remove substances, including antibiotics, from wastewater. These interactions are passive and nonmetabolic, allowing high-efficiency removal of contaminants. For example, after lipid extraction, *Chlorella vulgaris* and *Chlorella* sp. demonstrated significant adsorption of different compounds, such as metronidazole and cephalexin, respectively (Nguyen et al., 2020; Li et al., 2022).

Biodegradation is a fundamental process in nature and environmental engineering in which complex organic compounds are transformed into simpler products through enzyme-catalyzed reactions. This process occurs mainly in microorganisms, which use compounds as a source of energy or nutrients, resulting in the complete or partial decomposition of these organic materials (Tiwari et al., 2017; Li et al., 2022).

According to the table below, several applications of biological processes involving algae are highlighted, highlighting the versatility and usefulness of methods such as biodegradation and bioadsorption in solving environmental and industrial challenges, with a focus on removing these pollutants.

Table I: Biological techniques using algae to remove different pollutants.

Algae	Mechanism	Pollutant
Chlamydomonas sp.	Biodegradation	Tetracycline
Tetraselmis suecica	Biosorption	Tetracycline
Chlamydomonas sp	Biodegradation	sulfamethoxazole
Chlamydomonas sp.	Biodegradation	Sulfadiazine
Spyrogira sp.	Biodegradation	sulfathiazole
Cenadesmus dimorphus	Bioadsorption	Ciprofloxacin
Clorela vulgar	Biodegradation	Levofloxacin
Clorela vulgar	Biodegradation	Azithromycin
Microcystis aeruginosa	Biodegradation	Amoxicillin
Scenedesmus chlorelloides	Biodegradation	molybdenum
Chlamydomonas	Biodegradation	Lead
Chlorella vulgaris	Biodegradation	zinc, cadmium and copper
Oscillatoria spp	Biodegradation	zinc, cadmium and copper

Source: Adapted from Li et al., 2022.

According to Pedro and collaborators (2021), the genera *Chlamydomonas*, *Chlorella* and *Scenedesmus* stand out as frequent choices for bioassays designed to evaluate the toxicity of various contaminants in aquatic ecosystems. These microalgae provide effective and cost-effective assessments of environmental risks and play a crucial role in improving water quality. In addition to detecting toxicity, these species have the ability to significantly contribute to the purification of water bodies, especially by absorbing nitrite and phosphorus, making them valuable tools in environmental management initiatives and monitoring water resources.

ALGAE BIOFILTRATION TECHNOLOGIES

Algae are fundamental to the environment because they are primary producers and help maintain life in rivers, seas, and oceans. They are also crucial for biogeochemical cycles such as carbon and sulfur cycling. Furthermore, they benefit economically in diverse countries and are used for different purposes (Vidotti, 2004).

In the context of algae biofiltration in basic sanitation, the use of these organisms is highly promising due to their effectiveness in water purification. Integrating algae into treatment systems makes it possible to significantly reduce the need for chemicals, thus minimizing the adverse environmental impacts associated with their use. Furthermore, this approach promotes sustainable practices and represents an economically advantageous option for companies and governments (Vidotti, 2004).

Heavy metals, microorganisms, toxic chemicals, and fertilizers are examples of contaminants that spill into rivers and seas and that end up for human consumption when there is no adequate basic drinking treatment, causing serious damage to the population and the ecosystem (Trajano et al., 2020).

There has been an increase in the number of biotechnological studies in recent years, intending to generate profitable and more accessible basic sanitation; thus, research has emerged on the design of biofiltration systems using algae to remove these pollutants. An example is the Peru institution's study, where the macroalgae *Chondracanthus chamissoi* (Figure 2) was evaluated for removing heavy metals, such as chromium, using the biotechnological biofilter method. This study was successful in achieving a 100% absorption rate. In addition to being easily found in nature, algae can efficiently bind to metal ions (Siccha, 2014).

Figure 2: *Chondracanthus chamissoi*

Source: José Ávila Peltroche, biodiversity4all, 2015.

Some studies have used this system to reuse water, as in aquaculture. When water changes during certain periods of the year to remove nitrate and to save money, water is recirculated for management, benefiting from biofiltration by macroalgae, such as *Chaetomorpha* sp. (Holm-Hansen et al., 1963; Xu et al., 2010).

In 2019, Archimede Ricerche, an Italian company, developed a project to use algae to treat wastewater. In the project, during the water purification phase, *Spirulina* microalgae are placed in tanks next to the wastewater to be cultivated. Thus, in a favorable environment, with sunlight and pollutants that enrich their growth, such as nitrate, algae are stored through photosynthesis in their tissues and develop. This absorption contributes to water purification against contaminants and increases the amount of algae biomass available for other purposes, such as cosmetic production (Euronews, 2019).

PRACTICAL APPLICATIONS AND CASE STUDIES

Use of algae in water and sewage treatment plants

The use of algae in water and sewage treatment plants has gained prominence as a promising approach for improving water quality and reducing the load of pollutants in water bodies. Algae, particularly microalgae and macroalgae, have demonstrated unique abilities to remove nutrients and organic contaminants from effluents (Ho et al., 2019).

In water treatment plants, algae are often integrated into biofiltration systems to remove contaminants such as nitrogen, phosphorus, and organic matter. These photosynthetic organisms can absorb nutrients dissolved in water during their growth, helping to remove them from effluents efficiently. Furthermore, algae can contribute to water oxygenation through photosynthesis, further improving treated water quality (Smith et al., 2018).

In sewage treatment, algae also play an essential role in removing nutrients and purifying effluents. Algal lagoon systems, for example, are used to increase algal biomass in large volumes of wastewater, where algae absorb nutrients such as nitrogen and phosphorus for growth. Some common examples of microalgae used include *Chlorella*, *Spirulina*, *Scenedesmus,* and *Chlamydomonas*. Among macroalgae, species such as *Ulva*, *Gracilaria,* and *Enteromorpha* can be used. Furthermore, the photosynthesis carried out by algae in lagoons also helps to oxygenate water and decompose organic matter (Wang et al., 2020).

The successful implementation of algae-based water and wastewater treatment technologies depends on the appropriate selection of algal species, the efficient design and operation of systems, and the optimization of environmental parameters to promote algal growth and activity. Continuous research in this area aims to develop more effective and sustainable systems, aiming to meet the growing demands for water and sewage treatment around the world while promoting the conservation of water resources and the protection of the environment (Henderson et al., 2019; Xu et al., 2017; Martin et al., 2021).

Examples of communities or regions that have successfully implemented algae-based sanitation solutions

Several communities and regions worldwide have adopted innovative algae-based sanitation solutions to improve water quality, reduce pollution, and promote environmental sustainability. A notable example is the city of Qingdao, China, which implemented a sewage treatment system based on algae ponds. This system uses algae to remove nutrients such as nitrogen and phosphorus from sewage effluents, promoting the recovery of high-quality water for reuse and minimizing the discharge of pollutants into local water bodies (Xu et al., 2017).

Another success story is the pilot project in San Francisco, United States, where algae were integrated into drinking water treatment. In this project, algae were used in biofiltration systems to remove organic contaminants and improve the quality of treated water, contributing to reducing the use of chemical products and protecting local water resources (Smith et al., 2018).

Several coastal communities have also explored algae cultivation as part of effluent treatment and nutrient recovery strategies. For example, Noli in Italy has adopted macroalgae farming systems in its coastal waters to absorb nutrients and improve water quality while promoting sustainable aquaculture and marine ecosystem protection (Giacometti et al., 2020).

These examples highlight the potential of algae-based sanitation solutions to address the environmental and public health challenges associated with water and wastewater treatment. By adopting innovative and sustainable approaches, these communities demonstrate how algae can play a crucial role in improving water quality and promoting the health and well-being of local populations (Xu et al., 2017).

CONCLUSION AND PERSPECTIVES

In summary, the benefits of basic sanitation for algae are remarkable. As discussed throughout this chapter, algae have shown a unique ability to purify water, remove nutrients and pollutants from wastewater, and improve water quality in water and wastewater treatment systems. Furthermore, its application reduces the dependence on chemical products and promotes more sustainable practices in waste treatment.

In the future, the role of algae in continually improving sanitation and water quality is promising. With technological advances and growing awareness of the importance of environmental preservation, algae-based sanitation solutions are expected to be increasingly adopted in communities and regions worldwide. This trend is driven by the need to address global environmental challenges such as the scarcity of drinking water and water resource pollution.

Therefore, it is essential to continue investing in the research and development of technologies related to algae to optimize their effectiveness in water and sewage treatment. Furthermore, public education and awareness about the benefits of algae in basic sanitation are essential to promote its widespread implementation and ensure the long-term sustainability of these solutions.

In short, algae are fundamental for promoting public health, preserving the environment, and ensuring access to clean and safe water. By continuing to explore their potential and innovatively integrate them into sanitation systems, we can achieve significant advances in water quality and promote human well-being on a global scale.

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