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Review article

Ecology of freshwater harmful euglenophytes: A review

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ABSTRACT

A diverse array of aquatic ecosystems are inhabited by the euglenophytes, a group of autotrophic and eukaryotic organisms. In inland waterbodies, the red bloom is caused by a rapid development or accumulation of euglenophytes. Recent studies have designated euglenophytes as bioindicator of organic pollution. The ecology of euglenophytes is influenced by the changes in the intensity of sunlight, temperature, nutrient cycles, and seasons. Most of the species of euglenophytes grow prolifically with the increase of water temperature. Nitrogen and phosphorus are often thought to be the main nutrients that influence the cellular growth of toxic euglenophytes. A high concentration of nutrients is required for the euglenophytes to grow and to form bloom. Heavy bloom of euglenophytes in the summer season is the characteristic of eutrophic ponds. Inland waterbodies in many countries suffer from euglenophyte blooms, which shade submerged vegetation, deplete the dissolved oxygen and disrupt the aquatic food webs. Dense bloom of euglenophytes clog the gills of fishes, cause breathing difficulties and in extreme cases results mortality. Red blooms of the deadly toxin producing *Euglena sanguinea* negatively affect the water quality resulting massive mortality of fishes. Consequently, aquaculture systems and fisheries are facing a serious threat from the predicted outbreak of toxic red blooms of euglenophytes worldwide. To ensure sustainability in the fisheries and aquaculture industry, it is essential to analyze the ecology of euglenophytes. Again, interesting research on euglenophycin, a *Euglena*-derived natural product, has shown that it can be utilized as a potential anti-cancer drug. This paper comes up with a thorough review of the latest research in this area, revealing new insights and solutions that can help mitigate the negative impact of the freshwater harmful euglenophytes. By implementing considerable management strategies, the health of the valuable aquatic ecosystems and the future of the aquaculture and fisheries can also be secured.

1. Introduction

The euglenophytes are microscopic, photosynthetic, and planktonic microorganisms that occur abundantly in eutrophic waters. A broad range of free-living protists are classified as euglenophytes, which includes phototrophs, phagotrophs, and osmotrophs, as well as bacteriophags [1–3]. A key characteristic of the species of euglenophytes is their ability to store carbohydrates in paramylon [4], which has a unique b-1,3 link structure that differs from alpha linkages in higher plant starches, and their ability to move through the

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water column with flagella and through freshwater and estuarine sediments via metabolism [5]. Freshwater, saltwater, moist soils and mud rich in organic materials are the most common habitats for euglenophytes. *Euglena* sp., *Phacus* sp. and *Trachelomonas* sp. are the most ubiquitous and abundant species of Euglenophyta, which are responsible for blooms formed at the water surface during different seasons [6]. The distinctive euglenoid pigment astaxanthin gives these organisms a distinctive pink or red colour [7,8]. According to scientists [9–11], astaxanthin is a fat-soluble xanthophyll that is reddish-orange in colour. Various microalgal lineages and organisms contain it, including chlorophytes, dinoflagellates, prasinophytes or euglenophytes, as well as fishes, crustaceans and birds.

In recent decades, toxic euglenophyte blooms have been observed in eutrophic water bodies more frequently with their stunning brick red colour. In Bangladesh, for example, noxious euglenophyte bloom occurrences have been significantly increased over the past 10 years (Fig. 1). Euglenophytes overabundances can cause problems by shading submerged vegetation, disrupting food web dynamics and structure, and depleting dissolved oxygen [12–14]. Fish often have difficulty breathing in surface water during heavy blooms due to algae sticking to their gills. As a result, the fish eat less and lose weight [15], which ultimately impedes their growth [16–19].

Blooms of euglenophytes directly cause fish mortality through toxin ingestion. Conversely, euglenophyte blooms can cause fish mortality indirectly through trophic transfer disruptions and diseases or indirect oxygen effects. Euglenophyte blooms can also affect aquaculture operations to lose revenue [20]. In the 21st century, toxic euglenophytes blooms have been reported to produce alkaloids that cause tangible losses to aquaculture systems [21]. The toxin euglenophycin is produced by dense blooms of euglenophytes [22]. In a study published by Zimba et al. [23], euglenophycin was demonstrated to be ichthyotoxic, herbicidal, and anticancer. *Euglena sanguinea* is the most common euglenoid species found in toxic blooms [24]. Furthermore, a dense bloom of euglenophytes inhibits the

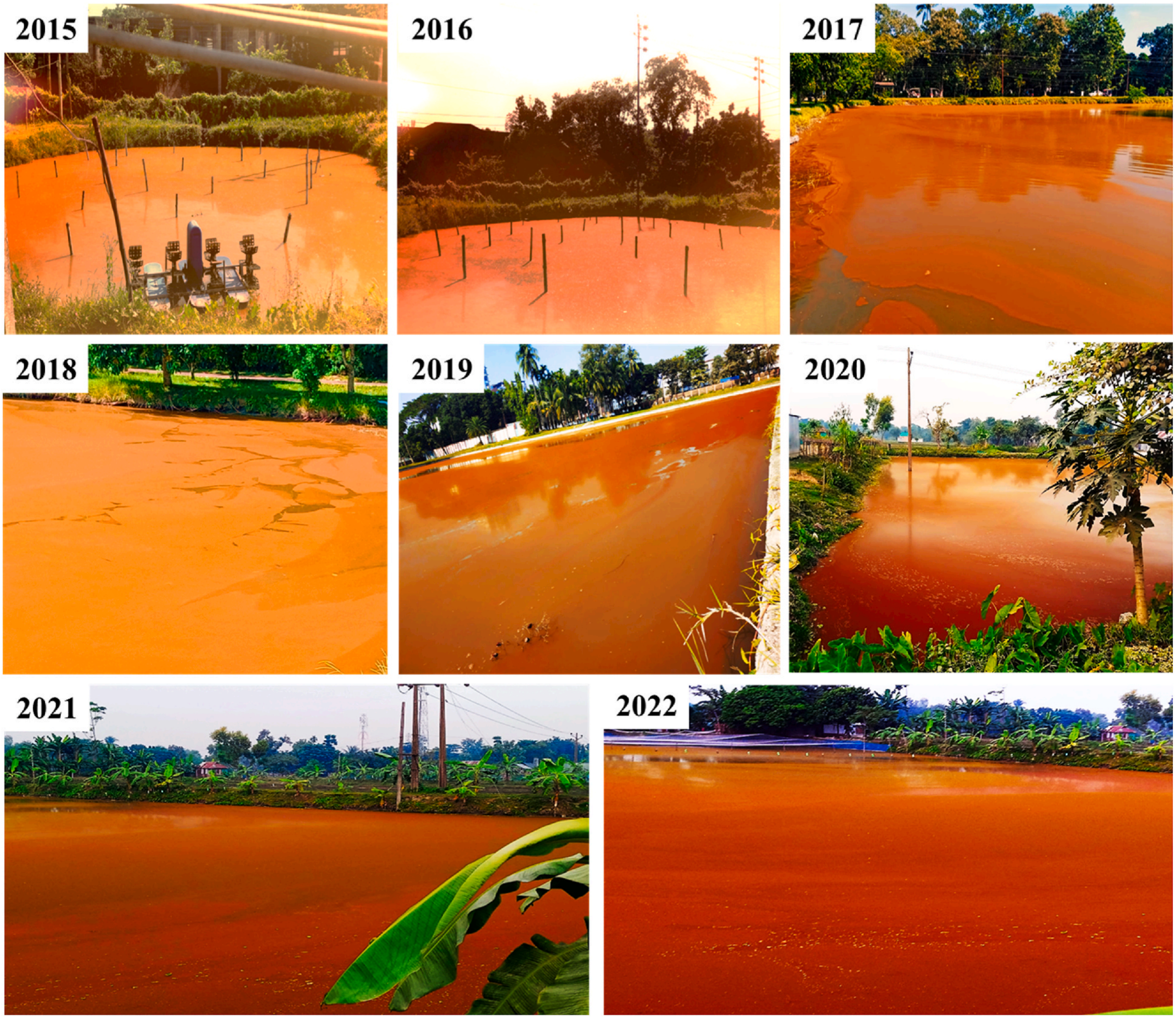

Fig. 1. Intense harmful red bloom of *Euglena sanguinea* in different waterbodies in Mymensingh, Bangladesh (Photographs were taken by the authors in August each year). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

growth of edible beneficial phytoplankton by reducing oxygen levels and obstructing the passage of light [25]. Also, they use nutrients from the water body for their growth, resulting in fewer natural food sources for fish.

There are a number of factors that affect the abundance and richness of euglenophytes, including sunlight, water temperature, pH, dissolved oxygen, and excessive nutrients [16,26,27]. In ponds and lakes, eutrophication results from nutrient enrichment caused by decomposition of organic matter, fertilizers, and supplementary feeding to fishes, frequently resulting in a dense bloom of euglenophytes. The presence of high nitrogen and phosphorus concentrations [16,28,29], heavy metals [29], and an acidic pH [30] are conducive to euglenophyte blooming. The highest density of euglenoid species was reported to be observed in acidic environments during elevated nutrient values, temperature, and biological oxygen demand (BOD) [30]. The abundance of euglenophytes is found to be highest in summer, winter, and autumn in tropical waters [16,31]. In various seasons, researchers observed the water colour at conventional and industrial fish farms to understand the concerning situation of euglenophytes.

In recent years, microalgae have become popular in nano- and micro-technology for their utilization in industrial applications, antibiotics, toxicity, productivity, water quality monitoring, and as indicators of water pollution [32–34]. As reliable indicators of organic contamination, the euglenophytes are investigated primarily for their ecological significance as phytoplankton [35,36]. There has also been a great deal of interest in this phytoplankton group because of the abundance of red sticky scum on the surface of the waterbodies, which often contributes to environmental degradation and hampers or reduces fish production.

Toxic and noxious blooms of the euglenophytes in eutrophic waterbodies are a common phenomenon in both developed and developing countries. However, there is still a lack of crucial information about the ecology of this particular group of microalgae under different environmental conditions. In order to manage harmful euglenophyte blooms and increase sustainable fish production, it is essential to clearly understand the ecology of the euglenophytes and their effects in eutrophic waterbodies. This review aims to examine the intricate ecology of the euglenophytes amidst the escalating prevalence of toxic euglenophyte blooms in eutrophic waterbodies, emphasizing their significant ramifications for global water quality, biodiversity, and aquaculture operations. Unlike previous reviews, it focuses on elucidating the drivers of euglenophyte blooms, including nutrient enrichment, environmental conditions, and toxin production, while exploring their direct and indirect effects on aquatic ecosystems and fish health. Emphasizing the need for sustainable management strategies, the review underscores the importance of integrating ecological knowledge with innovative technologies to mitigate the adverse impacts of euglenophyte blooms and ensure the long-term resilience of aquatic ecosystems and fish production.

2. Ecological distribution and occurrence of the euglenophytes

Euglenophytes are found in many countries around the world, including Indonesia, Israel, Tajikistan, Ukraine, Vietnam [37], Korea [38], India [29], and Bangladesh [16]. There are some species in the microalgal community those have a worldwide distribution, while others have a relatively restricted geographical distribution. Euglenophytes have a high number of microorganisms within morphospecies, their rapid movement, and low or unknown rates of allopatric and non-allopatric speciation account for the widespread distribution of these microorganisms [39].

There is a worldwide distribution pattern of euglenophytes [40]. Freshwater habitats are home to the majority of these widely distributed organisms, while brackish or marine habitats are home to a small percentage of these organisms [2]. In shallow lakes, marshes, and oxbow lakes, euglenophytes frequently create blooms [41–44]. Blooms of euglenophytes in large lakes and reservoirs are, however, well documented [45,46]. They can also be found in harsh habitats, such as acidic, warm, or heavy metal-containing biotopes. Depending on habitats of different environment, euglenophytes act like both heterotrophic and autotrophic as well as exhibit symbiotic characteristic and adapt vesicles that prevent them from drying out in a low moisture area. The fact that they reproduce rapidly, can produce cysts, and eat foods that are mixed together allows them to thrive in unfavourable environments [47]. This uniqueness proves that the euglenophytes can diversify from the acidic warm mud pools into fresh or saline water.

Thirteen toxic euglenoid blooms in freshwater aquaculture ponds were documented in the United States (mainly North and South Carolina, Texas, Arkansas, and Mississippi) at the beginning of the twenty-first century [24]. Euglenoid toxic bloom events in North and South Carolina, Texas, Arkansas, and Mississippi were mainly dominated by *E. sanguinea*, which was isolated, cultured, and

Table 1
Examples of abundantly occurring euglenophytes in different countries.

Countries	Dominant taxa of Euglenophyta	References
Bankura, West Bengal, India	*Euglena*	[50]
Thiruvananthapuram, India	*Euglena deses*, *Trachelomonas hispida* and *Trachelomonas volvocina*	[51]
Karnataka, India	*Euglena*, *Phacus* and *Trachelomonas*	[52]
Iraq	*Euglena*, *Lepocinclis*, *Phacus* and *Trachelomonas*	[53]
South Korea	*Trachelomonas*	[54]
Bangladesh	*Euglena*, *Phacus* and *Trachelomonas*	[48];
Nepal	E. sanguinea	[55]
Poland	*T. caudata*, *T. hispida*, *T. intermedia*, *T. volvocina* and *T. volvocinopsis*	[49]
South Africa	*E. sanguinea*	[56]
Thailand	*E. sanguinea*	[57]
Turkey	*E. sanguinea*	[58]
Spain	*E. sanguinea*	[59]

identified as a cause of fish mortality. The occurrence of euglenophytes has also been reported from Australia and Africa (Triemer and Zakrys, 2015). The presence of euglenophytes is common in eutrophic waterbodies of many other countries like Bangladesh, Thailand, Nigeria, China, India, Nepal, etc. ([48–50]; Table 1). Based on nutrient availability and geographical location, euglenophytes have different distributions and species compositions.

3. Major species of the euglenophytes those form red bloom

In planktonic communities, euglenophytes are also known as euglenoids, which are associated with high nutrient concentrations. There have been over 3000 species discovered during the last two centuries (3200 validly published names are recorded in Algaebase at http://www.algaebase.org). When present in large numbers, euglenoids tend to colour the water red, but only a small number of species have been recognized for this characteristic.

An alga called E. sanguinea causes the reddish colour of the waterbodies [59]. In literature, this is one of the earliest autotrophic euglenoid species described [60]. The blood-red colour of the cells of this species initially intrigued the scientists, but later it appeared that this was not a permanent characteristic [61]. Several types of carotenoids are present in *Euglena* cells, which produce the red blooms on the surface of water [62]. The red colouration of *E. sanguinea* during heavy bloom is primarily due to the red carotenoid pigment (WoRMS, 2011; Zimba et al., 2017). In *E. sanguinea* cells, haematochrome movement is affected by the intensity of sunlight, and this, coupled with positive phototaxis, leads to changes in water colour. High abundance (1628.4 ± 70.4 number/L) of *E. sanguinea* due to higher temperature and total nitrogen content of the water produce red bloom in summer [63]. There are also other *Euglena* species that occasionally display red pigmentation, such as *E. rubra*, *E haematodes*, *E. rubida*, *E. flava*, *E. orientalis*, *E. purpurea*, and *E. heliorubescens* [61].

Euglena species are well known for the alluded phenomenon, but there are other euglenoid species capable of producing blooms as well. Among these species are *Phacus mangini, Phacus pleuronectes, Phacus morii, Phacus tortus, Trachelomonas lefevrei, Trachelomonas scabra, Trachelomonas hispida, Trachelomonas abrupta*, *Trachelomonas ellipsoidalis, Trachelomonas abrupta, Trachelomonas similis, Lepocinclis ovum* and *Trachelomonas volvocina*. In Poland and Thailand, euglenoid species such as *Phacus triqueter, Trachelomonas volvocinospsis, T. rugulosa*, etc., bloomed at a rare rate [64].

There is a high chance of seeing red blooms in marshy areas and in waterbodies that have high organic loads. In Brazil, the United States, the Himalayas, Nepal, Nigeria, and in the Czech Republic, blooms of the euglenophytes caused dense red scums or red discolouration of the water ([62,65–67]; Mandal, 2016; [68]). Moreover, red blooms affect the concentration of the dissolved oxygen in the water and impact the appearance of the water, shade the lower waters, prevent photosynthesis and block sunlight penetration [21, 23]. A red bloom of euglenophytes eventually hampers the production of beneficial plankton [69]. According to Rahman et al. [16], some bloom forming genera of the euglenophytes reduce the number of other microalgal species in aquaculture ponds. In addition, Rahman et al. [70] found that the blooms of the euglenophytes significantly reduced the density of the chlorophytes and the bacillariophytes in the fish ponds.

4. Environmental influence on the ecology of the euglenophytes

The ability of the euglenophytes to quickly adapt to changes in the environment has made them excellent bio-indicators [71]. Species diversity in any water body is determined by a number of processes occurring at various spatial and temporal scales, including factors such as colonization and extinction, as well as biotic and abiotic interactions in the natural ecosystem. Community structure is determined by all of these factors [72]. Different research findings have been reported about the connections between environmental parameters and growth of euglenophytes throughout the world [28,73,74]. It is evident that certain environmental parameters interact with the euglenophytes and play a significant role in its diversification [75].

Ecological parameters play a significant role in determining the distribution of the euglenophytes. Researchers have studied the growth and development of the euglenophytes in response to temperature, organic matter, and albuminoid ammonia [52,76]. A number of variables, such as sunlight, temperature, nutrient concentrations, and light intensity, determine the development of the red bloom forming microalgae, such as *E. sanguinea* [77]. They can be abundantly found in waters above 20 °C [44,78,79]. Rahman et al. [48] found the highest cell densities of euglenophytes at around 30 °C water temperatures. The highest abundance of euglenoid species is also observed at high water temperatures by several studies [80,81]. For example, the optimum growth of many species of Euglena and Phacus is noted at high temperatures [82].

Khan et al [83] explained eutrophication in waterbodies due to a variety of environmental factors. In addition to the decomposition of organic wastes and unutilized feed in aquaculture ponds, the direct application of fertilizers causes eutrophication [83]. Aquaculture systems frequently develop dense blooms of euglenophytes as a consequence of eutrophication. During decomposition of the organic wastes, nitrates and phosphates are generated in greater amounts which stimulate the growth of the euglenophytes, as it was reported in case of *T. volvocina* [84]. During photosynthesis in the presence of sunlight, most of the euglenophytes absorb inorganic nitrogen and phosphorus. Their phagocytosis or absorption of dissolved organic molecules results in them becoming mixotrophic overnight. Euglenophytes grow prolifically when phosphate concentrations are higher in the environment [85]. There is considerable evidence that the euglenophytes can thrive in small waterbodies with high concentrations of phosphorus and nitrogen compounds, including ammonium salts [48,86]. Rahman et al. [16] registered 1.37 mg/L of PO_4–P and 1.47 mg/L of NO_3–N during the heavy bloom of euglenophytes in earthen experimental fish ponds of Bangladesh. In Brazil, the value of PO_4–P and NO_3–N concentrations was observed 0.35 mg/L and 0.15 mg/L during the *E. sanguinea* bloom in fish breeding tanks [15]. Small, shallow ponds and ditches in Thailand heavily laden with ammonium salts were found to contain 64 species of *Phacus* and two taxa of *Monomorphina* (Duangjan et al., 2014). In different parts of Thailand, Chaimongkhon et al. (2014) found organisms belonging to *Euglena, Lepocinclis*, and *Phacus*. Furthermore, water flow restrictions affect euglenophyte growth [84].

A pH of around 6.5 is most conducive for heavy bloom of euglenophytes [6]. According to Xavier et al. [15], pH levels during the bloom of *E. sanguinea* were found around 6.9. *Euglena gracilis* also grow optimally at acidic pH (pH $<$ 7.0) [82]. In another study, Rahman et al. [16] reported that the euglenophytes thrive in environments with pH levels lower than 8.0. *Euglena gracilis* and *E. mutabilis* both grow best at pH 2.5 to 7.0 [30]. Moreover, the growth of *E. mutabilis* and *E. gracilis* has been observed at elevated protons as well as elevated metals (Al, Cd, Cu, Fe and Zn). A high biochemical oxygen demand and a high concentration of free carbon dioxide coupled with a low concentration of dissolved oxygen can also influence the multiplication of the euglenophytes [87].

5. Diurnal vertical migration of the euglenophytes

Diurnal vertical migration of the euglenophytes occurs when they swim up to the surface before dawn and descend to deeper levels at dusk [88]. More than a century has passed since Fauvel and Bohn [89] published the first investigation on diurnal vertical migration of the microalgae. The behaviour of the vertical migrating cyanobacteria, dinoflagellates, euglenoids, and diatoms have been documented since then [90,91]. The intensity of sunlight is one of the most important abiotic factors that influence the diurnal vertical migration mechanisms of the euglenophytes. When there is adequate light intensity, they can easily photosynthesize, and when there is no light, they can ingest nutrients by phagocytosis. Depending on the intensity of light, the euglenophytes can also move up and down of the water column by negative gravitaxis and phototaxis, respectively. As it moves through the water column, this group is able to remain in places with the best lighting, which is essential for its survival and growth.

Several microalgae, including the euglenophytes, exhibit circadian rhythms [92]. Euglenophytes move toward the surface before the beginning of the light period and disperse from the surface before the start of the dark period according to a circadian rhythm [93]. It appears that the population of the euglenophytes is concentrated at the surface of the water during the day, but at night there is no apparent peak of abundance of the euglenophytes. With the passage of time, the colour of the water in bloom forming waterbodies varies; it is green at dawn and twilight when the sun is oblique and light intensity is low, and it is red during midday when sunlight intensity is high ([16,94]; Fig. 2).

Researchers have also shown that pigment positions can change in response to light intensity ([95]; Laza-Martinez et al., 2019). Red globules quickly move from the center of the cell to the periphery to cover chlorophyll when exposed to intense sunlight. This changes

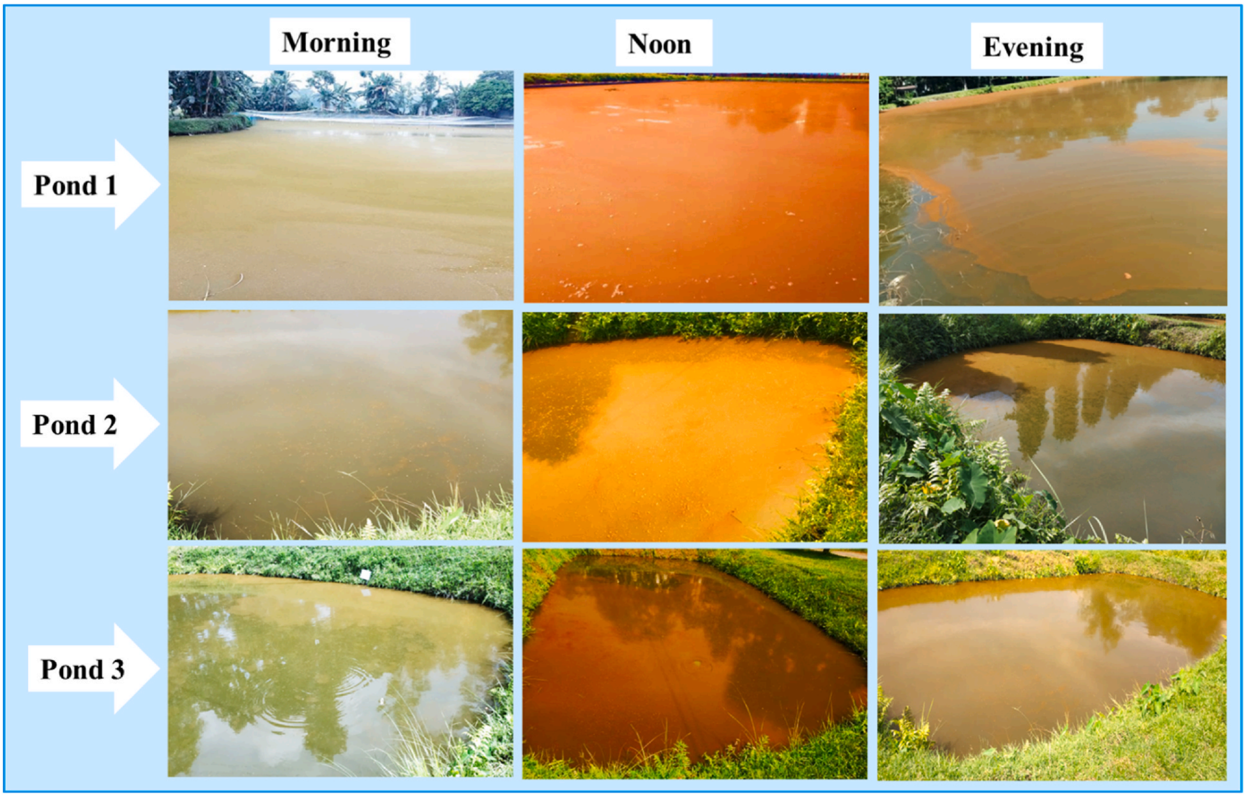

Fig. 2. Blooms of euglenophytes in three ponds in Mymensingh, Bangladesh: Water colour change in different time periods (morning, noon and evening) of a day with changes in light intensity (Photographs were taken by the authors in August 2022). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

the colour of the cell from green to red. Reddening can be seen at a much larger scale than at the cellular level as E. sanguinea generates large floating colonies, and the mechanism is one of the quickest and most dramatic colour changes attributed to photosynthetic organisms (Laza-Martinez et al., 2019). On a sunny day, the bloom first appears greenish in the morning and becomes reddish as the day progresses. *E. sanguinea* cells may be present at the surface of the water, but they travel downward after sunset and turn green in the late afternoon and evening (Laza-Martinez et al., 2019). Kingston [96] investigated the vertical migration of *Euglena* sp. on the sand banks of a piedmont stream in North Carolina and found that the stream become red by the upward migration of this species, reaching densities of 2200 cells per square millimeter by mid-afternoon. A total of 6 cm of sediment was found to contain live *Euglena* cells in triplicate sediment cores. During the day, over 80 % of the population was found within 2 mm depth from the surface. During the night, 75 % of the population was observed between 2 cm and 6 cm below the surface [96].

Red blooms of euglenophytes were found to be disappeared during heavy rainfall and it gradually reappeared in two to three days after the rain stops and the days are sunny. The mean population of euglenophytes, including *E. sanguinea*, was found to be decreased when the intensity of the sunlight was low due to cloudy weather [97]. Azizullah et al. (2012) reported the rapid decrease in the density of E. sanguinea in the absence of sunlight that further indicates the importance of light for the proliferation of this microalgae.

6. Seasonal abundance of the euglenophytes

The abundance of microalgae can vary greatly with the variation of temperature, pH level, and nutrient concentrations of an aquatic environment [98]. It is the tolerance levels of certain species that determine their dominance during various seasons. In euglenophytes, seasonal trends are temperature-dependent. As a result of changes in water temperature, the pattern of euglenoid biomass become fluctuated. Seasonal abundance of the euglenophytes has been well documented in numerous aquatic ecosystems. Ponds and lakes with eutrophic conditions often form red mats of euglenophytes in summer and autumn. It produces the appearance of "red water" or "red scum" as a result of the red pigment within algal cells.

Higher species richness of euglenoids were found in summer in eutrophic reservoirs in Central Mexico and lakes in Tumakuru district, Karnataka, India [52,99] (Fig. 3). An investigation of a fish pond in Chitwan district, Nepal revealed that the density of *E. sanguinea* and *E. proxima* was highest in summer compared with winter, autumn, and spring [63] (Fig. 4). In Bangladesh, euglenoids were observed to be bimodal in distribution, with maximum growth during winter and early summer [16]. Based on Rahman et al. [70] and Affan et al. [100], the number of euglenophytes with *Euglena* as its dominant genus increased from autumn through winter, peaking in late autumn and early winter. The seasonal abundance of the euglenophytes within ponds in a given location or different region may be affected by global warming and climate change even within similar ecological conditions. There has been an increase in global warming and climate change over the past two decades. Changing environmental conditions force the organisms to adapt in the changing environments in order to survive.

7. Toxin production by the euglenophytes

The incidence of problems associated with harmful algal blooms, especially euglenophytes, in aquaculture systems has been increasing and becoming more concerning in many countries. In waterbodies, harmful microalgae such as cyanobacteria [101], haptophytes [102], dinophyceans [103], and at least one species of Euglenophyceae can produce toxins [23]. Euglenophycin is a newly discovered toxin ([23]; Fig. 5) which has been isolated, purified, and designated from Euglenophyceae (*E. sanguinea*). The identification of the harmful euglenophytes in aquatic environment was initially challenging because of poor or insufficient published report

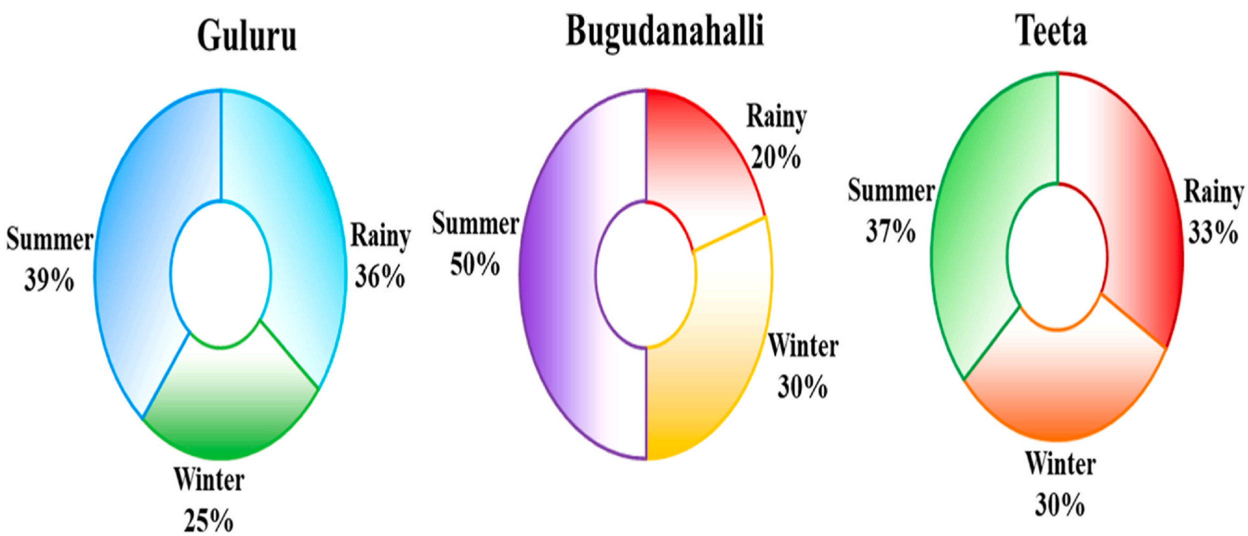

Fig. 3. Seasonal abundance of the euglenophytes in three selected lakes in Tumakuru district, Karnataka, India [52].

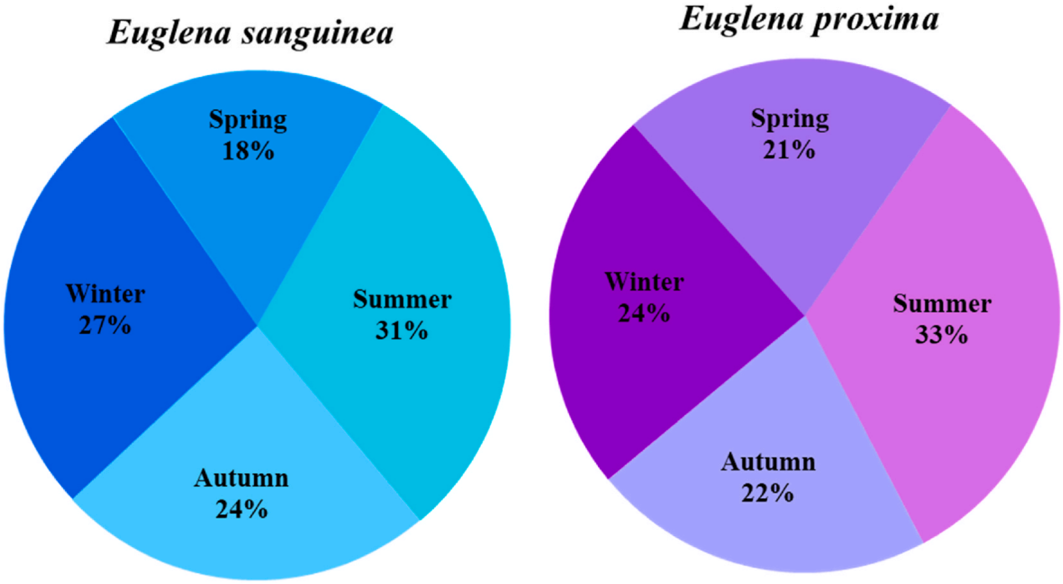

Fig. 4. Seasonal variations of *E. sanguinea* and *E. proxima* in a fish pond in Chitwan district, Nepal [63].

on fish mortality caused by this microalga [15].

The alkaloid toxin euglenophycin was initially identified as being produced by *E. sanguinea* [24]. In addition to *E. sanguinea*, seven other species of the euglenophytes are reported to produce euglenophycin. A number of species were studied, they were *Euglena sociabilis*, *Euglena stellata, Euglenaria clavata, Euglenaria anabaena, Strombomonas borystehnienis, Trachelomonas ellipsoidalis*, and *Lepocinclis acus* [22]. According to Kardinaal and Visser [104], the two top toxin-producing euglenophytes species (*E. sociabilis* and *E. sanguinea*) accumulate 100- and 1000-fold more euglenophycin than the other taxa. The prevalence of this toxin in aquatic environments has been linked to unexpected mass mortality of fish [23,48,105]. Freshwater aquaculture systems were first reported to be affected by euglenophycin exposure (Zimba et al., 2004). Zimba et al. [23] also reported several fish fatalities in aquaculture systems in several US states following the preliminary findings (Table 2). In aquaculture systems, catfish (*Ictalurus punctatus*), tilapia (*Oreochromis niloticus*), and striped bass (*Morone saxatilis*) died, resulting in the loss of revenue. As a result of exposure to the poisonous blooms of *E. sanguinea*, fish displayed disorientation, increased respiration, and difficulties maintaining equilibrium. Across the globe, euglenophycin has led to a variety of troubling symptoms, including decline and collapse of fisheries in the laboratory and in the field. The situation of harmful euglenophyte blooms has been getting worse, and the production of euglenophycin as a result of dense blooms has become more prevalent, posing a greater threat to aquatic organisms [106,107].

In addition to being highly ichthyotoxic, euglenophycin has unknown toxicological characteristics, but it is attracting attention for its ability to inhibit the proliferation of tissue cells in mammalian cancer cell lines. Wahome et al. [108] speculated that this toxin may be useful in fighting cancer. Euglenophycin also inhibits the growth of mammalian N2a cancer cells at low doses [23,109]. In a study, euglenophycin exhibited strong cytotoxicity toward N2a cells at a concentration of 25 μg/mL, resulting in a 50 % loss in the viability of the cells [108]. Due to its ability to target a number of cancer-promoting pathways, euglenophycin is a promising anti-colorectal cancer medication [110].

7.1. Constraints and strengths of the study

The review faced challenges due to the heterogeneity in study designs, limited availability of high-quality data, interdisciplinary complexity, resource limitations, and scope definition issues. However, it was compensated with strengths by providing a comprehensive understanding on the euglenophytes, including taxonomy, ecology, and toxin production, supported by robust scientific evidence. Visual aids like photographs, figures and tables enhanced clarity, while the well-organized informations aided comprehension. Identification of key species, such as *Euglena sanguinea*, helped to know the valuable insights. Furthermore, the study's global relevance, exemplified by events like the red bloom in Bangladesh, underscores its significance to diverse scholarly communities.

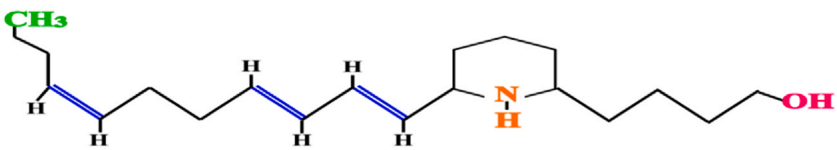

Fig. 5. Chemical structure of euglenophycin [23].

Table 2
Loss of revenue from fish mortality caused by toxin-producing *E. sanguinea* (Adopted from Ref. [21,23]).

Time	Location	Species of fish died	Euglenophytes cell density (Cells/ml)	Fish mortality rate (%)	Loss of revenue (US $)
July–August 2002	North Carolina (field, laboratory)	*Morone saxatilis* (Striped bass), *Oreochromis aureus* (Blue tilapia)	Unknown	100 %	1,00,000
August 2002	Mississippi (laboratory)	*Ictalurus punctatus* (Channel catfish)	3500	100 %	Unknown
November 2002	Mississippi (laboratory)	*Ictalurus punctatus* (Channel catfish)	982	100 %	Unknown
January 2003	South Carolina (laboratory)	Sheepshead	1345	100 %	Unknown
July 2003	Texas (field)	*Ictalurus punctatus* (Channel catfish)	2600	100 %	35,000
July 2003	Arkansas (field)	*Ictalurus punctatus* (Channel catfish)	1560	100 %	33,000
September 2003	Mississippi (field)	*Ictalurus punctatus* (Channel catfish)	750	0.01 %	120
June 2005	Mississippi (field)	*Ictalurus punctatus* (Channel catfish)	450	100 %	62,000
April 2006	Mississippi (field)	*Ictalurus punctatus* (Channel catfish)	10,000 (scum)	100 %	65,000
May 2009	Mississippi (field)	*Ictalurus punctatus* (Channel catfish)	1200	0.01 %	35,000

8. Conclusion

Euglenophytes, with their varied ecology and ability to grow in different water environments, present significant challenges to water quality and biodiversity when their populations rapidly increase, causing red blooms. These blooms, fueled by nutrient enrichment and influenced by factors like temperature and pH, are increasingly observed globally in freshwater bodies. They disrupt ecosystems by shading vegetation, altering food webs, and depleting dissolved oxygen levels, posing direct threats to fish health and aquaculture. Additionally, the production of toxins by some species of the euglenophytes exacerbates these challenges, contributing to fish mortality and revenue loss. Understanding the ecological dynamics of the euglenophytes, including their seasonal abundance, diurnal migration patterns, and toxin production, is crucial for effective management strategies to mitigate the harmful impacts of the euglenophyte blooms. Sustainable fish production and water resource management demand comprehensive research efforts aimed at elucidating the complex interactions between the populations of the euglenophytes and environmental conditions. Integrating ecological knowledge with innovative technologies and management practices can help minimize the adverse effects of the blooms of the euglenophytes and promote the resilience of aquatic ecosystems for future generations.

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Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

CRediT authorship contribution statement

Sunzida Sultana: Data curation, Formal analysis, Methodology, Writing – original draft. **Saleha Khan:** Conceptualization, Funding acquisition, Investigation, Project administration, Supervision, Writing – review & editing. **Nowrin Akter Shaika:** Data curation, Resources. **Sadia Momota Hena:** Data curation, Resources, Software. **Yahia Mahmud:** Writing – review & editing. **Md Mahfuzul Haque:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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