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Physicochemical Properties and Microalgal Diversity of Sabon Gari and Rimaye Fish Ponds, Nasarawa State, Nigeria

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Abstract

Despite the growing interest in microalgae for their ecological and biotechnological value, there is a lack of detailed studies on the diversity and physicochemical dynamics of microalgae in fish ponds within underexplored regions like Nasarawa State, Nigeria. This study examines the isolation, identification, and physicochemical properties of microalgae in Sabon Gari and Rimaye fish ponds in Nasarawa State, Nigeria, an unexplored area for microalgal resources. Water samples from the ponds were cultured in Blue-green 11 Medium and analyzed for microalgae composition and environmental factors affecting pond health and productivity. Morphological identification revealed the presence of Chlorella sp., Microcystis sp., Scenedesmus sp., and Coelastrum sp. in Sabon Gari Pond, and Euglena sp., Chlamydomonas sp., Scenedesmus sp., Chlorella sp., and Oscillatoria sp. in Rimaye Pond. These species have significant biotechnological applications in biofuel production, renewable energy, water quality management, and pharmaceuticals. The physicochemical analysis revealed significant differences between the ponds in parameters such as pH, dissolved oxygen, biological oxygen demand, chemical oxygen demand, turbidity, water hardness, and chloride ions. However, electrical conductivity, total dissolved solids, temperature, nitrate, phosphate, copper, and zinc levels were not significantly different. Nitrate (2.11 mg/L) and phosphate (4.34 mg/L) levels in Sabon Gari Pond were higher, promoting microalgae proliferation, while lower dissolved oxygen (9.19 ± 0.64 mg/L in Sabon Gari and 11.17 ± 0.88 mg/L in Rimaye) indicates early eutrophication, potentially reducing fish yield. Zinc and copper levels were within WHO limits, and no lead was detected. These findings highlight the environmental factors influencing aquaculture productivity in the ponds and emphasize the potential of microalgae for biofuel production, water treatment, and other applications, while also identifying risks posed by eutrophication. It is recommended that regular monitoring and management of nutrient levels be implemented to avert eutrophication. Furthermore, the identified microalgae should be investigated further for their biotechnological applications in renewable energy and water treatment, aiming to boost both environmental sustainability and economic benefits in the region.

Keywords: Eutrophication, Heavy metals, Microalgae, Physicochemical properties, Ponds

INTRODUCTION

Algae encompass a diverse and heterogeneous group of organisms from numerous phyla, characterized by distinct physiological attributes. Microalgae thrive in various aquatic environments, including freshwater, marine water, and wastewater streams from agricultural run-offs, concentrated animal feed operations, and industrial and municipal sources. Some species also can grow on rocks, soils, plants, etc. as long as there are adequate required amounts of C (organic or inorganic carbon), N (ammonium, nitrate, urea, yeast extract, etc.), and P (Phosphorus) as well as other essential trace elements required (Tarique and Monitahana, 2014). Microalgae are crucial components of aquatic ecosystems, contributing to oxygen generation, nutrient cycling, and serving as a fundamental food source for aquatic life. Akinyemi et al. (2022) identified various microalgae species in the Osun fish pond, including *Spirulina* sp., *Microcystis aeruginosa*, *Phacus* sp., *Chlorella vulgaris*, *Scenedesmus dimorphus*, *Pediastrum* sp., *Scenedesmus quadricauda*, *Euglena* sp., and *Pinnularia* sp. Similarly, Ribeiro et al. (2019) found *Pseudokirchneriella subcapitata* and *Coelastrum* sp in open ponds.

Their diverse biochemical properties make them valuable for various biotechnological applications, including biofuel production, wastewater treatment, toxicity studies, and the formation of bioactive compounds (Badamasi & Sani, 2019). The high lipid content and ability to produce bioactive substances in microalgae make them promising candidates for biofuel development and other industrial uses (Morton and Steve, 2008; Rani *et al*., 2018). Moreover, Paul et al. (2020) noted that these microorganisms can produce pigments like chlorophyll and carotenoids, which have extensive potential applications as chemical dyes and coloring agents. Furthermore, microalgae contribute significantly to carbon sequestration, helping mitigate global climate change. The physicochemical characteristics of water influence the biotic connections of organisms in water bodies, including their ability to withstand pollution loads and provide nutritional balance (Shokunbi *et al*., 2021). Algal growth factors include temperature, light intensity, nutrient type and quantity, CO2 levels, and pH. The great diversity among algae species results in varying growth requirements. Environmental conditions in a specific area can significantly impact microalgal populations and their growth dynamics. Consequently, it is essential to investigate the relationship between water quality parameters and microalgal communities, and how these factors affect the suitability of ponds for fish farming and ecosystem dynamics. Despite the promising potential of microalgae, knowledge about species composition and uses of strains found in most tropical areas of Africa and other unexplored regions remains limited (Chia *et al*., 2013; Azeez *et al*., 2021; Akinyemi *et al*., 2022). The diversity of microalgae is affected by environmental factors such as nutrient availability, light, temperature, pH, and water chemistry. This diversity is ecologically significant and hold great biotechnological potential. Exploring and bioprospecting algae from undiscovered locations may be crucial for expanding their industrial applications. It is important to screen indigenous microalgae for various human uses, biotechnological applications, and strains that adapt to local environmental conditions. This study aimed to isolate and identify microalgae species from the Sabon Gari and Rimaye fish ponds and evaluate the physicochemical parameters of the water samples.

MATERIALS AND METHODS

Study site and Sample collection

The water samples were collected from Sabon Gari and Rimaye fishpond located in Keffi Local Government Area, a traditional and commercial town in Nasarawa State, North-Central Nigeria, which is located between Latitude 8° 51' 48" North and Longitude 7° 49'. 29" East, at an elevation of 340 meters (1,115 feet). Keffi LGA covers 138 square kilometers and experiences average temperatures of 30 ° C. The dry and wet seasons are the two main seasons in the region, and the average humidity in the LGA is 42 percent (Sufiyan *et al*., 2020). This region is characterized by a humid and dry tropical or savannah climate. Operations such as integrated fish pond production involving concrete and clay ponds stocked with tilapia and catfish are carried out in these ponds (Oaya & Charles, 2017).

The experiment was carried out at the Biological Sciences Laboratory, Department of Biological Sciences, National Open University of Nigeria. Water samples were collected from Sabon Gari and Rimaye fish ponds using two different sample bottles: one for analyzing physicochemical parameters and the other for analyzing microalgae. The sample bottles were labeled with the date. Water samples containing algal species were collected in 500 ml sterile white bottles from the fish. The samples were first examined under a microscope to check for the presence or absence of microalgae. The water samples from each pond were filtered using sterile muslin cloth to recover a concentrated amount of microalgae. The microalgae were transferred to 20 ml of sterile medium (BG-11 medium).

Microalgal Analysis and Identification

Blue-green 11 medium preparation

The composition of the blue-green 11 medium comprised of 1 mL of the solutions mentioned in Table 1. The components were made up to 1 L with distilled water and the final pH made up to 7.4. The medium was then sterilised with an autoclave at 121 C for 15 mins (Andersen *et al*., 2005).

Table 1: BG 11 Medium Composition

S/N	Stock (Nutrients)	Quantity (g/L)
1	$NaNO_3$	30.0
2	$K_2HPO_4 \cdot 3H_2O$	8.0
3	$MgSO_4 \cdot 7H_2O$	15.0
4	$CaCl_2 \cdot 2H_2O$	7.2
5	$C_6H_8O_7 \cdot H_2O$ (Citric acid)	1.2
6	$C_{12}H_{22}FeN_3O_{14}$ (Ammonium ferric citrate green)	1.2
7	EDTA Na_2	0.2
8	Na_2CO_3	4.0
9	**Trace Metals**	
	a. H_3BO_3	1.43
	b. $MnCl_2 \cdot 4H_2O$	0.905
	c. $ZnSO_4 \cdot 7H_2O$	0.11
	d. $Na_2MoO_4 \cdot 2H_2O$	0.195
	e. $CuSO_4 \cdot 5H_2O$	0.04
	f. $Co(NO_3)_2 \cdot 6H_2O$	0.025

Isolation and Identification of Microalgae

Algal isolation was accomplished using both solidified and liquid Blue-Green 11 Media. Before using the medium, it was autoclaved at 121°C for 15 minutes and allowed to cool. One (1) milliliter of pond water was added to clean sterilized glass bottles containing BG 11 Medium. They were then wrapped with sterile cotton wool to allow for gas exchange while preventing contamination. They were put near a window for two weeks to get light radiation (Aneja, 2007). The streak plate technique was used to separate pure algal strains from cultivated plates. Individual colonies were selected from mixed populations and sub-cultured until a pure isolate was achieved. A sterile wire loop was used to form colonial streaks on the growth media. The plate was completely covered and sealed with paraffin, then inverted and incubated for 14 days at 25 °C. The microalgal composition of the water samples was determined and quantified using a light microscope. Microalgae were identified using normal taxonomic keys (van Vuuren 2006).

Physicochemical analysis of the fish ponds water samples

Determination of temperature and colour

Water temperature was monitored with a thermometer. The thermometer bulb was dipped into water at a depth of 2 cm and allowed to stabilize before readings were obtained and recorded in degrees Celsius (APHA, 2017). The colour was determined using the HACH DR 5000 spectrophotometer. A blank of ten millilitres (10 ml) was created using filtered de-ionised water. This was dispensed into a sample cuvette and used to zero the spectrophotometer by entering the programme number 120 at the 455nm wavelength for colour. The sample was also prepared through filtering. Then, 10 ml of the prepared sample for analysis was poured into the cuvette, read, and recorded in mg/L.

Determination of Turbidity, pH and Electrical Conductivity

The turbidity test was performed as described by APHA (2017), with a 10 ml portion of deionised water poured into a cuvette used to standardize the spectrophotometer, followed by 10 ml of each sample poured into another cuvette inserted into the spectrophotometer, and the reading was noted and recorded at 430 nm on the turbidity meter. The readings were averaged and recorded in NTU. Before taking the measurements, the pH meter was standardized with a pH 7 buffer. After immersing the pH probe in the water sample and letting it sit for a few minutes to stabilize the reading, the probe was rinsed with deionized water to prevent cross-contamination between samples (USEPA, 2014). Conductivity was measured using the ExTech-ExStik II EC500 model field kit, and the meter reading was recorded in µS/cm (APHA, 2017).

Determination of Total Hardness and Total Dissolved Solids

The APHA (2017) method titrimetrically measured the total hardness. In the presence of Erichrome black dye, 2 mL of ammonia buffer was mixed with 0.02M ethylene diamine tetra acetate (EDTA) solution to titrate about 20 ml of the water samples. The calculation of the total hardness is shown below.

Total hardness (mg/L) = $\frac{Volume\ of\ EDTA \times N \times 50 \times 1000}{Sample\ Volume}$

Similarly, the exttech-exstik II EC500 multimeter was used to measure the total dissolved solids (TDS). After turning it on and zeroing the reading, the electrode was dipped into the sample spot until the water covered the membrane. The readings were taken correctly and recorded in milligrams per litre (APHA, 1998).

Determination of Chloride ion, Nitrate and Phosphate

The Mohr method, which uses silver nitrate for titration (normality: 0.0141), was used to measure the amount of chloride ion. The silver nitrate solution was standardized against a standard chloride solution made from sodium chloride (NaCl). During the titration, the chloride ion precipitated as white silver chloride, and the indicator (potassium chromate) was added to visualize the endpoint, indicating the presence of excess silver ions. When excess silver ions were present, the solubility product of silver chromate was exceeded, resulting in the formation of a reddish-brown precipitate.

This phase proves that all chloride ions have been depleted and only the surplus silver ions have reacted with chromate ions: 1.0 ml of the indicator solution (potassium chromate) was introduced to a 100 ml sample in a conical flask. The pH of the sample was recorded. This was then titrated with a standard silver nitrate solution until a pale-yellow endpoint was reached, and the amount of titrant used was documented. The concentration of chloride ions was calculated using the equation provided below:

Chloride Ion Concentration (mg/L) = $(A \times N \times 35450)/_{V\ Sample}$

Where: A = volume of titrant used, N is the normality of silver nitrate (here we used N/71 or 0.0141 N), and V sample is volume of sample used (mL). Average of the replicates were taken and recorded in mg/l (APHA, 2017).

To ascertain the level of nitrate, a 100 ml sample of pond water was placed in a dry, clean crucible and dried in an oven set at 100 °C. The colour shift was measured at 430 nm using a colorimeter after it was taken out and allowed to cool. Two millilitres of phenol disulphoric acid were then added and spun around evenly for ten minutes. Ten millilitres of distilled water were then added, along with five millilitres of ammonia solution (APHA, 2017). A 250 ml conical flask was filled with 100 ml of the pond water sample, 1 ml of ammonium molybdate reagent, and 1 drop of stannous chloride. The mixture was then left to react for 12 minutes, and the colour changed read at 600nm to determine the phosphate level (APHA, 2017).

Determination of Heavy Metals and Preparation of Standard Solution

The concentration of selected heavy metals (copper, lead and zinc) were measured using the Atomic Absorption Spectrophotometer/AAS (Bulk Scientific). Approximately 100 ml of each water sample were acidified with 20 ml of nitric acid, and the mixture was digested in a fume cupboard for an hour at 100 °C until a clear solution was visible and the volume decreased to 20 ml. The mixture was then transferred to a 100 ml volumetric flask and diluted with deionized water until it reached the 100 ml mark. After cooling, the mixture was filtered with filter paper, and the heavy metals were measured using the Atomic Absorption Spectrophotometer (HACH D5000).

Standard solutions of selected metals were prepared by dissolving their respective salts in distilled water, using stoichiometric calculations based on molecular weight and atomic mass. For example, 3.93 g of copper(II) sulfate (molecular weight: 249.68 g/mol) was dissolved per litre, based on the atomic mass of copper (63.55 g/mol). The same method was applied to other metals: lead was prepared using lead nitrate $[(PbNO_3)_2]$, and zinc using zinc sulfate ($ZnSO_4$). The absorbance and calibration curve were established by preparing and analysing the standard solutions in the AAS. The heavy metal concentration was then directly read from the calibration curve. When the blanks were measured, distilled water was used in place of the test solution.

Data Analysis

Analysis of variance (ANOVA) was used to determine the significant differences, where there was statistical significance, Tukey's post hoc test was used to separate the means at $p < 0.05$ (5% significance level). Homogeneity of variance and normality tests were carried out using Levene's homogeneity of variance and Shapiro-Wilk tests, respectively, prior to ANOVA.

Principal Component Analysis (PCA) was used to determine the relationship between physicochemical parameters and relative abundance. Statistical analysis was performed using the R Software version 4.4.4 (Akinyemi & Olukunle, 2022)

RESULTS

Physicochemical characteristics of Sabon Gari and Rimaye fish ponds

The results of the physicochemical parameters analysed for Sabon Gari and Rimaye fish pond in terms of colour, odour, pH, total dissolved solids, COD, BOD, temperature, turbidity, water hardness, alkalinity, chloride, nitrate, phosphate, conductivity, zinc and copper showed significant variations in some parameters while others did not.

Conductivity, Alkalinity, Total Dissolved Solids and Dissolved oxygen

In this present study, the conductivity and total dissolved solids of Sabon Gari and Rimaye fish ponds showed no significant difference (p>0.05) however Rimaye showed the highest conductivity and the lowest TDS of 170 µs/cm 24 ppm and Sabon Gari recorded 168µs/cm and 27 ppm respectively. The highest alkalinity was observed in Rimaye fish pond at 35 mg/L while Sabon Gari recorded 34 mg/L, and there was no significant difference between the two fish ponds (P>0.05). The level of dissolved oxygen showed significant variation (p<0.05) between Sabon Gari (9.19 mg/L) and Rimaye Pond (11.17 mg/L) (Figure 1).

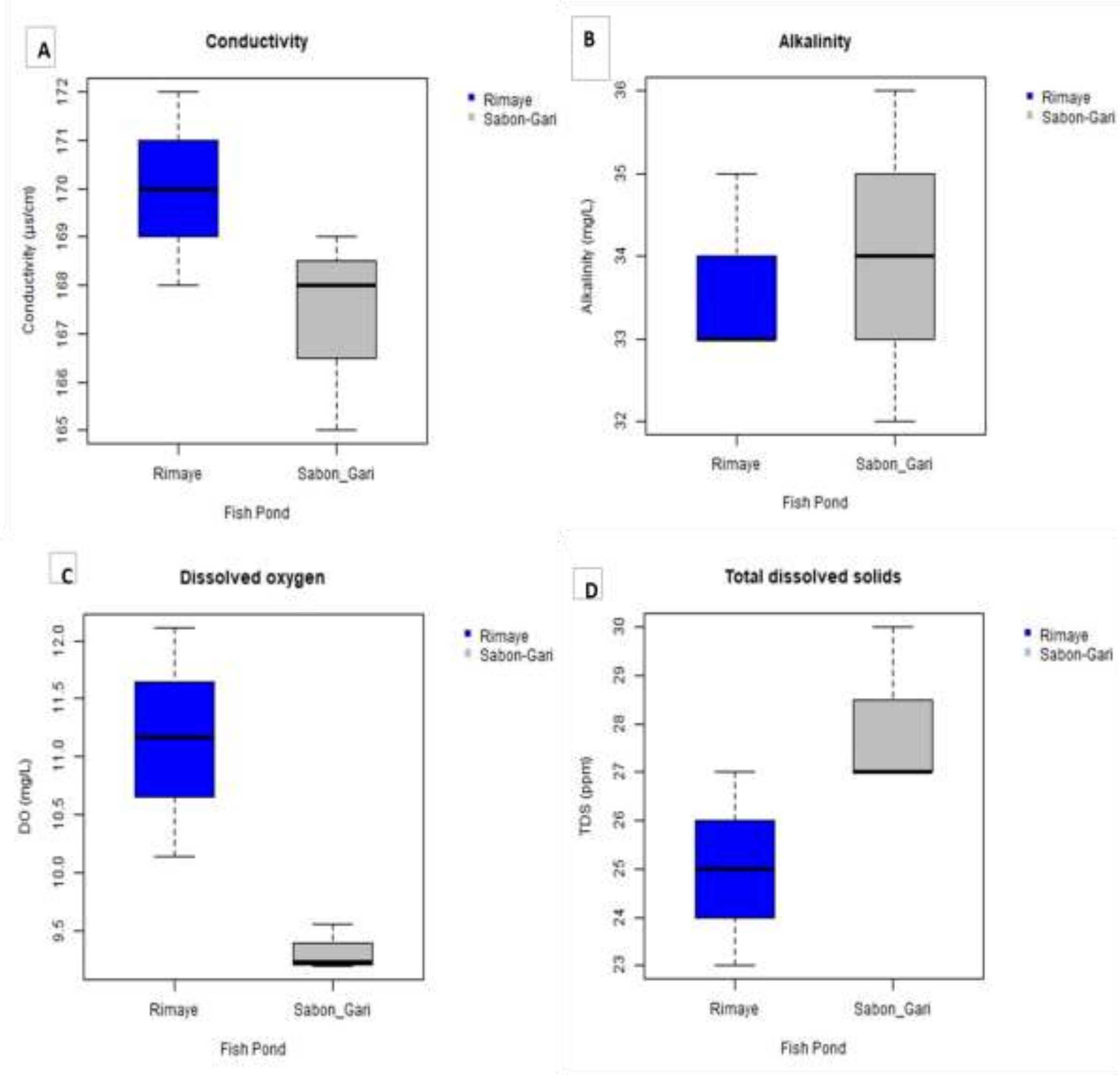

Figure 1: Conductivity (A), Alkalinity (B), Dissolved oxygen (C) and Total dissolved solids (D) of Rimaye and Sabon Gari fish pond. The middle bar in each box of the boxplots represents the median (or the 50th percentile) of the data distribution for that variable, while the outer bars represent the interquartile range.

Biological dissolved oxygen, Chemical oxygen demand, pH and Temperature

The levels of BOD and COD in Sabon Gari and Rimaye ponds revealed significant variations ($P<0.05$) with Rimaye pond recording the highest dissolved oxygen (11.17 mg/L) while Sabon Gari had the highest BOD and COD 4.28 mg/L and 88 mg/L respectively. The pH values for the Sabon gari and Rimaye fish pond indicate significant variation at $p<0.05$. The pH for Sabon Gari and Rimaye fish ponds was recorded at 9.1 and 7.4 respectively. No significant difference was observed in the temperature of the two fish ponds (Figure 2).

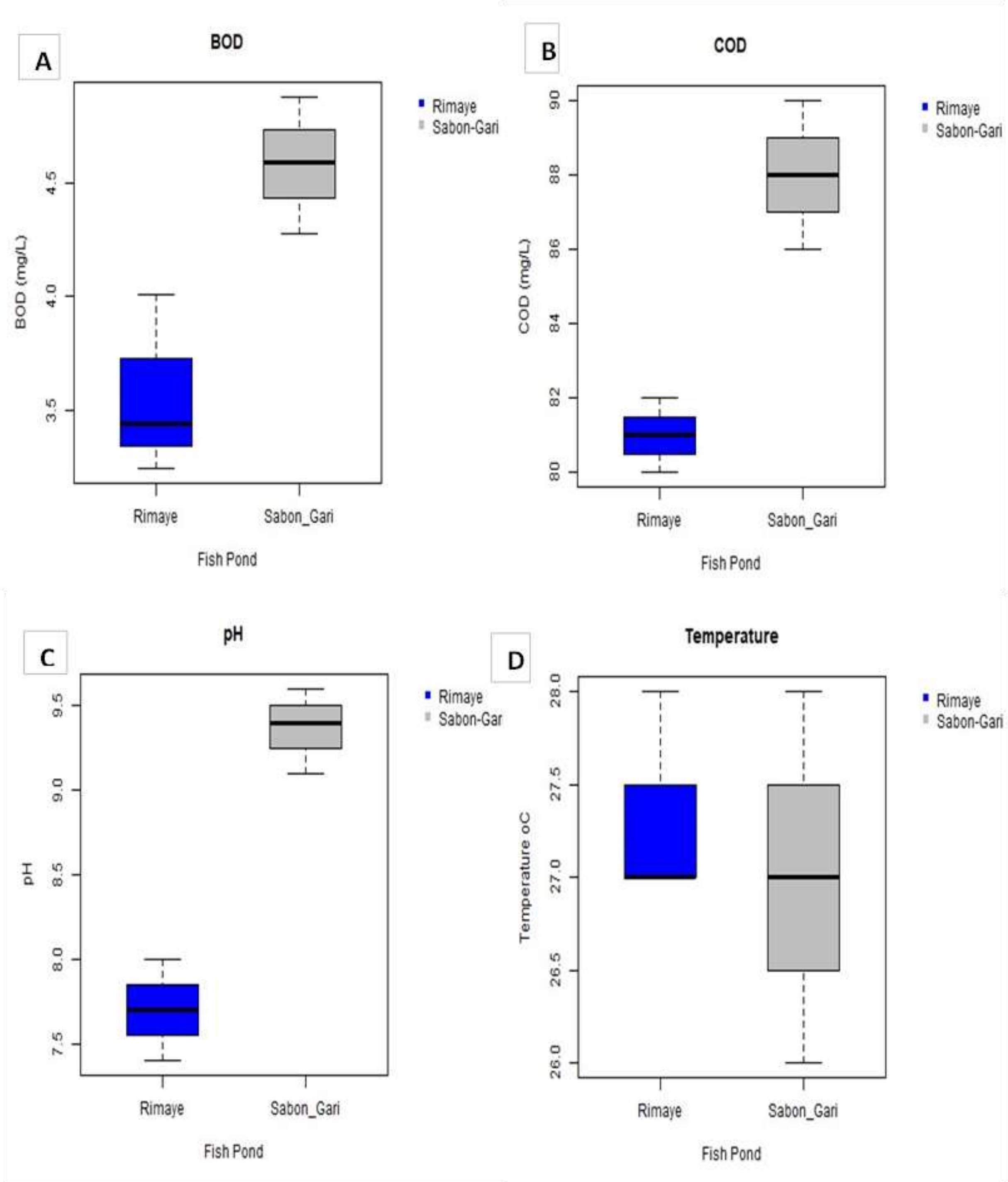

Figure 2: Biological dissolved oxygen (A), Chemical oxygen demand (B), Ph (C) and Temperature (D) of Rimaye and Sabon Gari fish pond. The central line in each box of the boxplots indicates the median (or the 50th percentile) of the data distribution for that variable, whereas the external lines illustrate the interquartile range.

Turbidity, Water hardness, Nitrate and Chloride ions

In the present study, the turbidity values of the Sabon Gari and Rimaye fish ponds showed a significant difference ($p<0.05$). The Sabon Gari fish pond recorded 157 NTU while of Rimaye fish pond detected 135.10 NTU. Sabon Gari fish pond recorded the highest value (2.67 mg/L) of water hardness compared to Rimaye (1,23 mg/L) and there was a significant difference 9$p<0.05$) between the two ponds. The concentration of chloride ions in Sabon gari fish pond was significantly ($p<0.05$) higher 14.94 mg/L than that of Rimaye fish pond (7.13 mg/L). However, the nitrate content recorded for Sabon Gari (2.11 mg/L) and Rimaye (2.3 mg/L) did not reveal any significant difference and values are within the WHO standards (Figure 3).

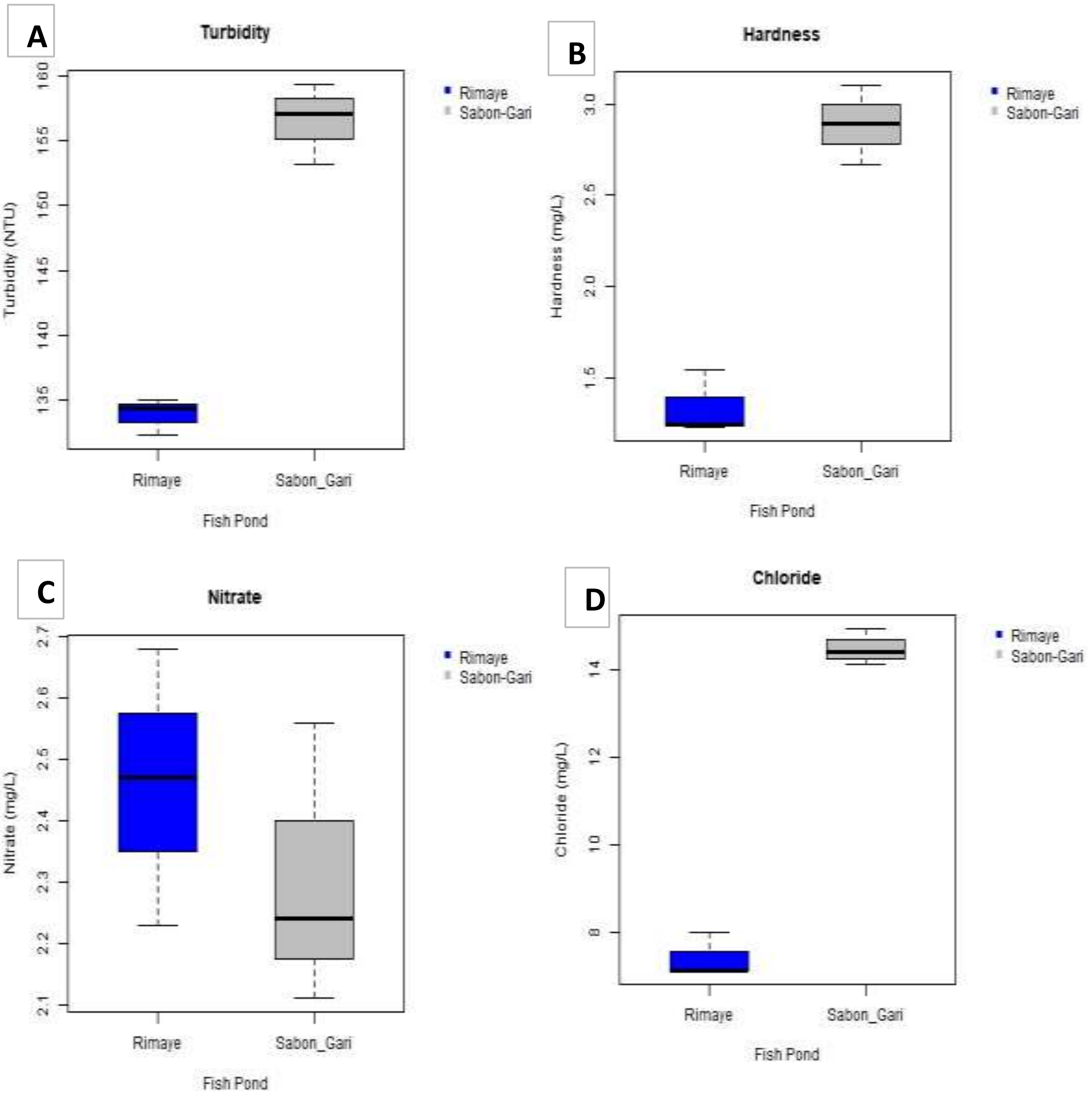

Figure 3: Turbidity (A), Water hardness (B), Nitrate (C) and Chloride ions (D) of Rimaye and Sabon Gari fish pond. The middle line in each box of the boxplots represents the median (or the 50th percentile) of the data distribution for that variable, while the outer lines depict the interquartile range.

Heavy metals, Water colour and Phosphate

The heavy metal concentration results indicated that both Rimaye and Sabon Gari ponds had lower concentrations of zinc (0.02 ppm). The concentration of copper was higher in Sabon Gari (0.02 ppm) compared to Rimaye (0.01 ppm).

However, no lead was detected in either sample. The heavy metal levels were within acceptable ranges for aquatic ecosystems. The colour of the water sample in Sabon Gari was 9 TCU while that of Rimaye fish pond recorded 11 TCU which were all within the WHO limits and showed no significant difference. More so, the phosphate content of Sabon Gari pond was 4.34 mg/L while Rimaye recoded 4.01 mg/L without showing any significant difference (p>0.05) (Figure 4)

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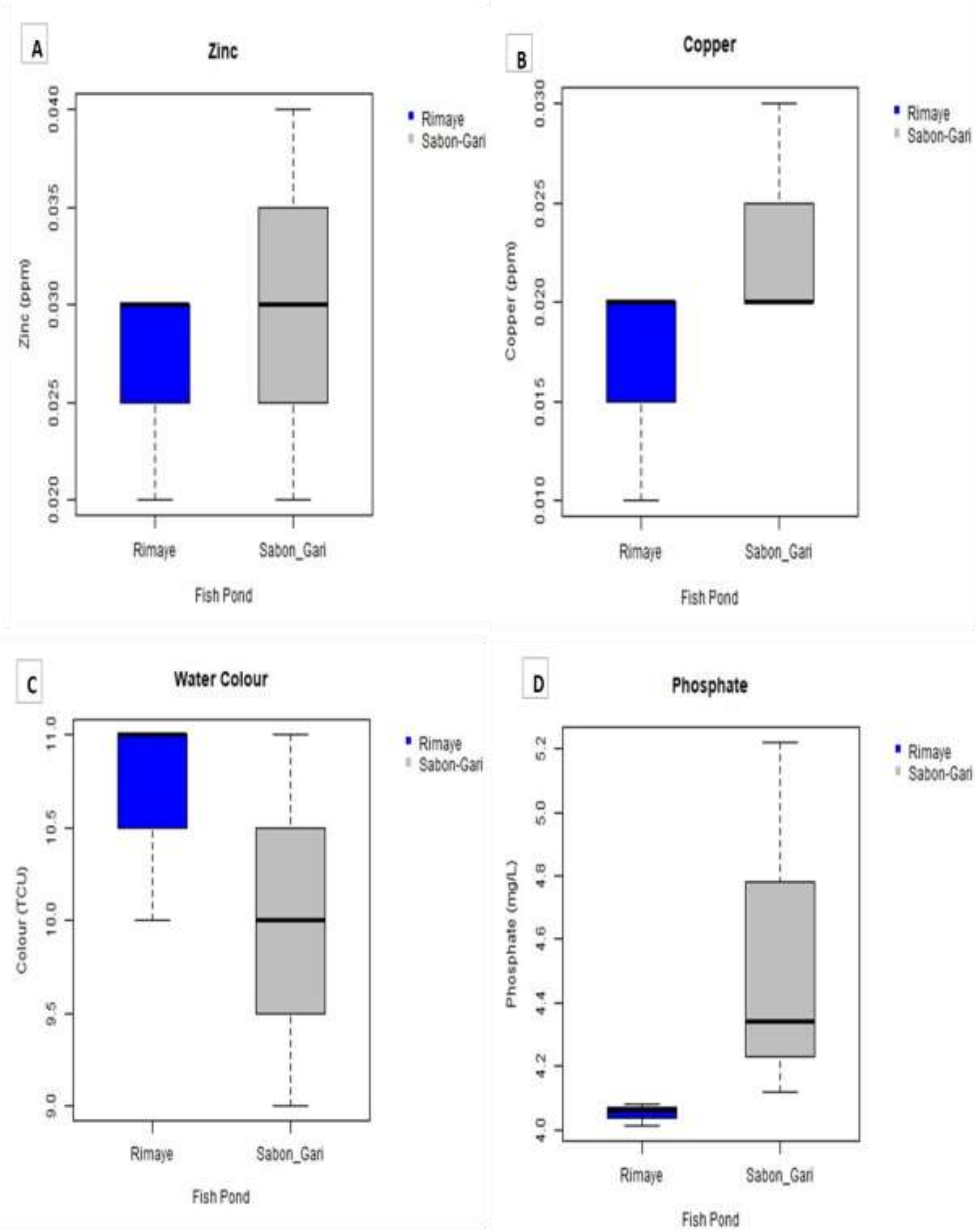

Figure 4: Zinc (A), Copper (B), Water colour (C) and Phosphate (D) of Rimaye and Sabon Gari fish pond. The median of the data distribution for each variable is represented by the central line in every box of the boxplots, while the external lines demonstrate the interquartile range.

Principal Component Analysis of Physicochemical Parameters and Relative Abundance of Microalgae Species

Physicochemical parameters and relative abundance of microalgae species showed the first two principal components, representing 82.9% of the total variation in the data generated from the experiments. Conductivity was negatively correlated with alkalinity and total dissolved solids however, turbidity revealed a positive correlation with COD, water hardness, total dissolved solids and alkalinity. The nitrate levels and dissolved oxygen showed positive association with *Oscillatoria* sp., *Euglena* sp., *Chlamydomonas* sp. and *Chlorella* sp. in Rimaye fish pond. Chloride ion and BOD favours the growth of *Scenedesmus* sp., *Microcystis* sp., and *Coelastrum* sp. in Sabon Gari pond (Figure 5).

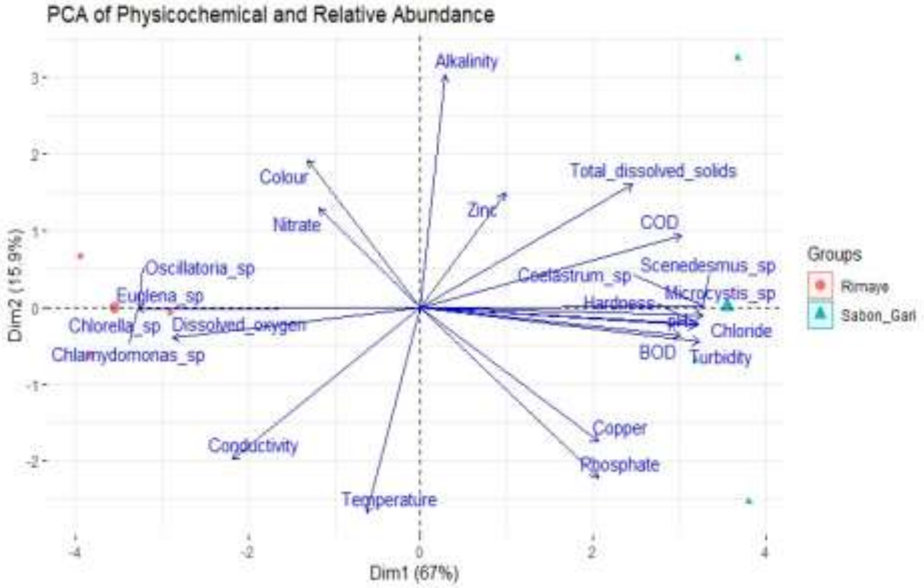

Figure 5: Principal component analysis of physicochemical parameters (Alkalinity, Hardness, Conductivity, BOD, COD, Temperature, pH, Colour, Chloride, Nitrate, Copper, Phosphate, Zinc, Dissolved oxygen, Total dissolved solids, Turbidity and relative abundance of microalgae species. Variables on opposing axes are negatively related, while those grouped on the same orthogonal axis are positively correlated.

Microalgae species composition in the fish ponds

Four species of microalgae (*Microcystis* sp., *Coelastrum* sp., *Scenedesmus* sp., and *Chlorella* sp.) were identified in the Sabon Gari fish pond. These species were classified into two divisions: Cyanobacteria and Chlorophyta. In the Rimaye fish pond, five species (*Scenedesmus* sp., *Euglena* sp., *Chlamydomonas* sp., *Chlorella* sp., and *Oscillatoria* sp.) were observed and grouped into three divisions: Euglenophyta, Chlorophyta, and Cyanobacteria (Figure 6).

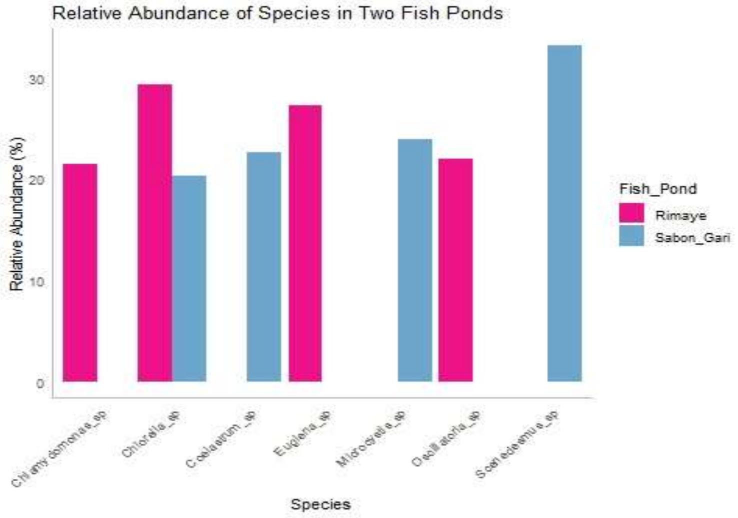

Figure 6: Percentage of relative abundance of microalgae species in Rimaye and Sabon Gari fish pond

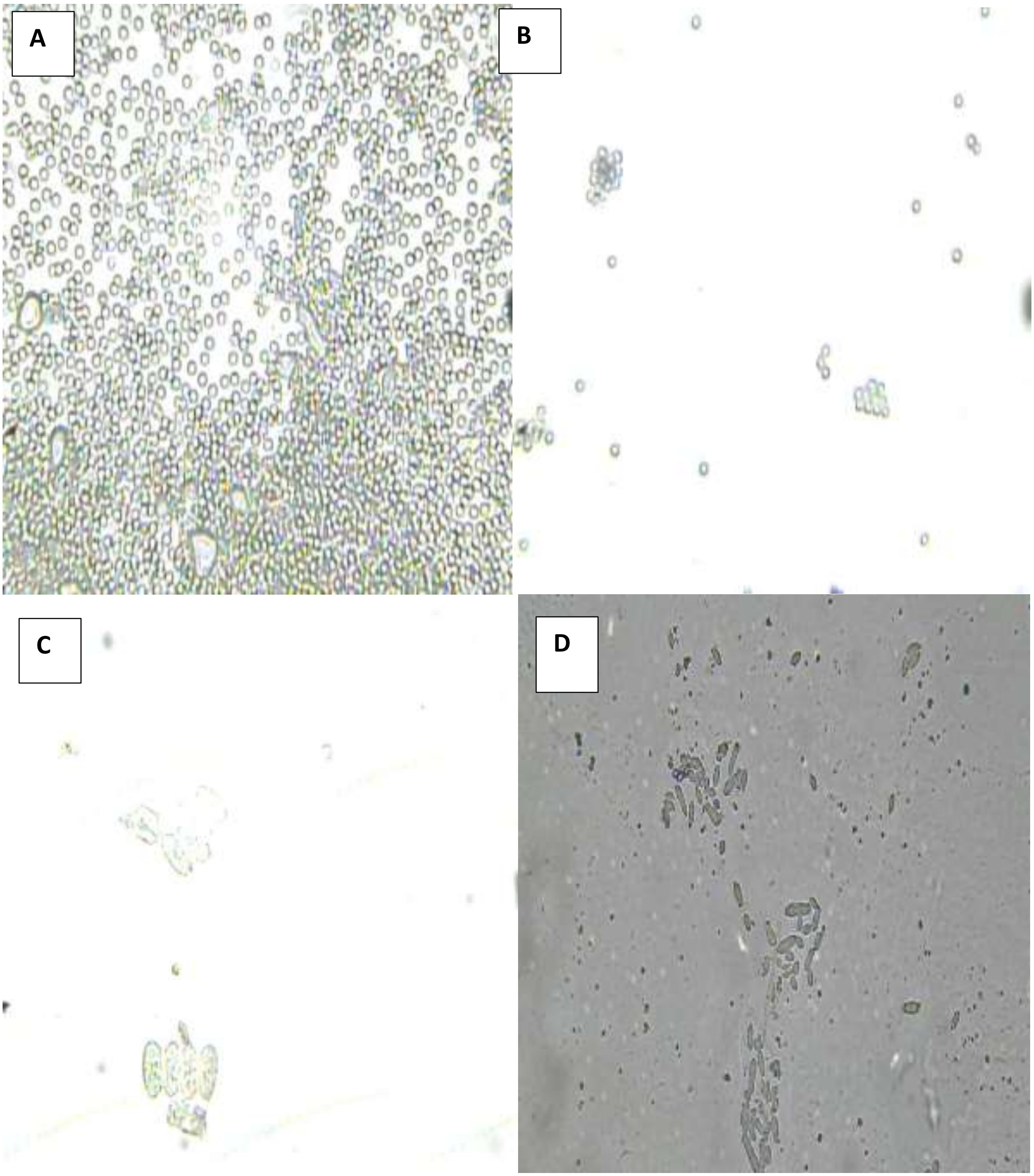

Plate 1: Microalgae species isolated from Sabon Gari and Rimaye fish pond in Nasarawa state. *Microcystis* sp. (A), *Coelastrum* sp. (B), *Scenedesmus* sp. (C) and *Euglena* sp. (D).

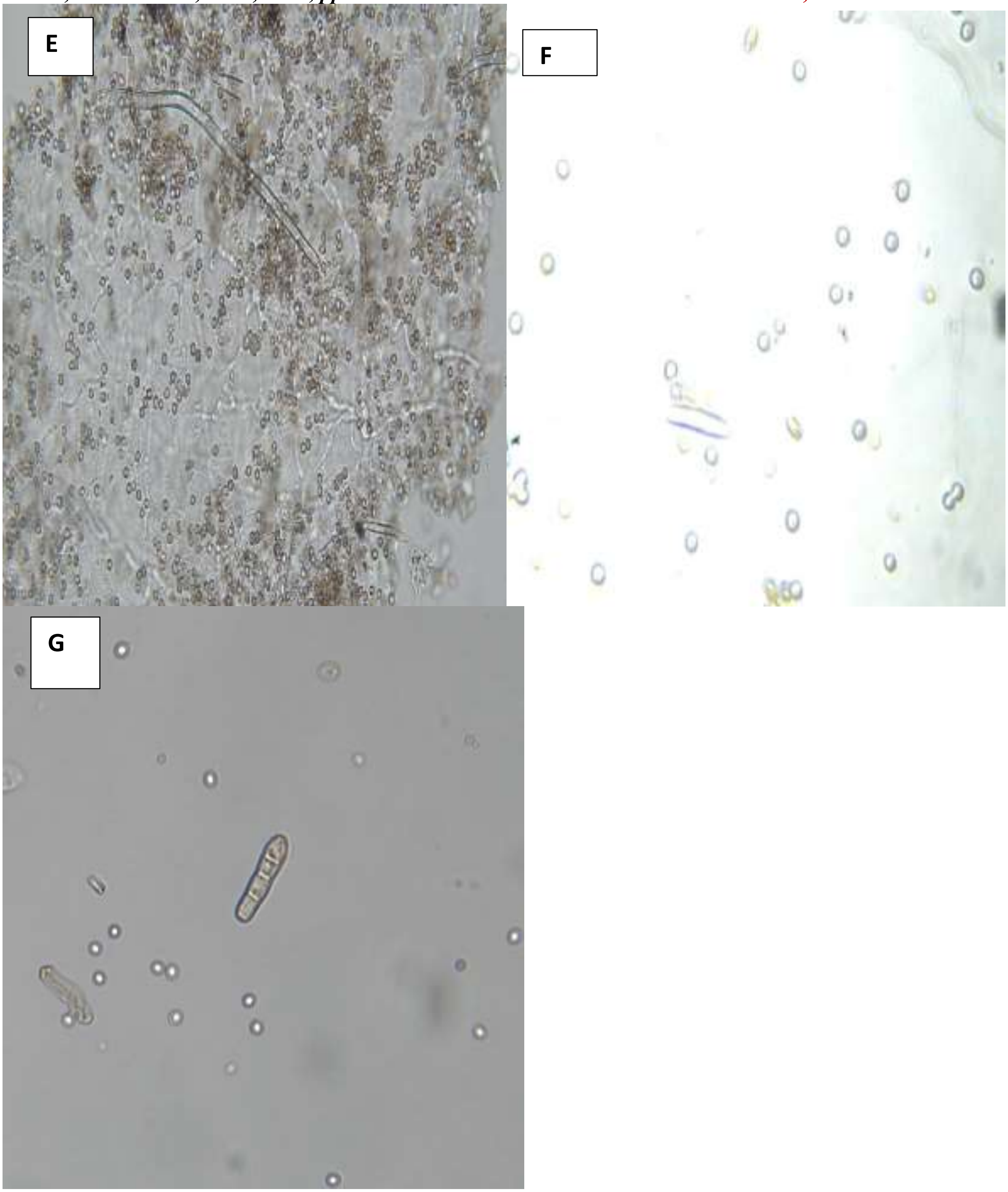

Plate 2: Microalgae species isolated from Sabon Gari and Rimaye fish pond in Nasarawa state. *Chlorella* sp. (E), *Chlamydomonas* sp. (F) and *Oscillatoria* sp. (G).

DISCUSSION

The study of Sabon Gari and Rimaye fish ponds in Nasarawa State, Nigeria, provides crucial information about these aquatic environments' microalgal composition and physicochemical characteristics. Significant differences ($p<0.05$) were observed between the two ponds in terms of pH, dissolved oxygen, biological dissolved oxygen, chemical oxygen demand, turbidity, water hardness, and chloride ion concentration. In contrast, no substantial differences ($p>0.05$) were found in conductivity, total dissolved solids, temperature, nitrate, colour, phosphate, copper, and zinc levels. Examining physicochemical factors such as pH, temperature, dissolved oxygen, nitrate, and phosphate levels provided an essential understanding of their impact on microalgae growth and ecosystem dynamics (Miranda and Krishnakumar, 2015; Etisa *et al.*, 2024).

The research indicated that the Sabon Gari pond had nitrate levels of 2.11 mg/l, while the Rimaye pond had 2.23 mg/l. These nitrate concentrations and comparable phosphate levels established conducive conditions for microalgal proliferation. The notable variation in pH (9.1 in Sabon Gari and 7.4 in Rimaye) and dissolved oxygen content (9.19 mg/L in Sabon Gari compared to 11.17 mg/L in Rimaye) indicates a need for specific interventions. Sabon Gari's elevated pH and reduced oxygen levels, along with higher BOD (4.28 mg/L) and COD (88 mg/L), suggest increased organic pollution and eutrophication risks, potentially harming fish health and productivity (Sinclair *et al.*, 2023). Regarding water hardness and chloride ions, Sabon Gari's greater hardness (2.67 mg/L) and chloride ion concentration (14.94 mg/L) highlight water quality concerns that may influence fish physiology, necessitating regular monitoring and possible water treatment (Menon *et al.*, 2023). The higher turbidity (157 NTU) and nutrient such as phosphate, with 4.34 mg/L) levels in Sabon Gari indicate eutrophication risks that could result in harmful algal blooms (HABs) and oxygen depletion (Bashir *et al.*, 2020).

To address these environmental impacts, the implementation of nutrient control methods, including regulated feeding and vegetation buffers, could be effective (Liu *et al.*, 2019). The water quality analysis reveals that the ponds are suitable for aquaculture, as evidenced by the absence of lead and the presence of zinc and copper within WHO-approved levels. Nevertheless, continuous surveillance is crucial to prevent potential contamination from nearby activities. The distinct characteristics of Sabon Gari and Rimaye ponds underline the need for tailored management approaches. Rimaye's more consistent water quality and varied microalgae population could be exploited for enhanced productivity, while Sabon Gari might require remedial actions to combat eutrophication and pollution.

The research successfully identified various microalgae species in both ponds, revealing significant differences between Sabon Gari and Rimaye. Sabon Gari pond exhibited a diverse microalgae community, including *Chlorella* sp., *Microcystis* sp., *Scenedesmus* sp., and *Coelastrum* species, which have considerable biotechnological applications (Oyewumi and Olukunle, 2018; Khan *et al.*, 2023). These species are valuable for biofuel production, water quality improvement, and various industrial uses. In contrast, Rimaye pond contained a different microalgal composition, comprising *Euglena* sp., *Chlamydomonas* sp., *Scenedesmus* sp., *Chlorella* sp., and *Oscillatoria* species, which are important for renewable energy, pharmaceutical development, and toxicity research (Wang *et al.*, 2022). The observed differences in microalgal species between the two ponds indicate that environmental factors significantly influence the composition of microalgal communities (Nega, 2021; Cai *et al.*, 2023). The detection of *Chlamydomonas* sp. in Rimaye and *Coelastrum* sp in Sabon Gari fish pond demonstrates their contribution to primary production in aquatic ecosystems.

Green algae of this variety enhance oxygen content and provide sustenance for diverse aquatic organisms, including fish. Recognizing these algae is essential for understanding fish pond productivity, which is vital for aquaculture and maintaining robust fish populations (Jusoh et al., 2020; Cai *et al.*, 2023). Microalgae are regarded as a third-generation biofuel resource owing to their capacity to generate high lipid content, which can be transformed into biodiesel. For example, species such as *Chlorella vulgaris* and *Scenedesmus obliquus* can accumulate substantial lipids, rendering them appropriate for biodiesel production (Khan *et al.*, 2023). Microalgae efficiently extract nitrogen and phosphorus from wastewater, which are primary contributors to eutrophication in aquatic ecosystems. Species like *Chlorella* sp. are renowned for their high lipid content (up to 50% of dry weight under optimized conditions). This microalga has been extensively researched for biodiesel production and can considerably decrease nutrient levels in treated water, enhancing overall water quality (Azeez *et al* 2021; Parichehreh *et al.*, 2021). *Scenedesmus obliquus* is not only proficient in biofuel production but also excels in nutrient removal from wastewater, making it suitable for integrated aquaculture systems. Research has shown that *Scenedesmus* can produce biodiesel with desirable fuel properties, including low viscosity and high cetane number (Ogbonna *et al.*, 2022). In India, *Scenedesmus* strains were successfully cultivated in wastewater for biofuel production, combining waste treatment with energy generation (Pandey *et al.*, 2019; Pandey *et al.*, 2024). Nevertheless, scaling up production is capital-intensive, necessitating technological advancements in harvesting, lipid extraction, and conversion processes to achieve economic viability.

Although *Microcystis* sp. are typically associated with harmful algal blooms, certain varieties can be utilized for biotechnological purposes, such as biofuel production in controlled settings (Choudhary *et al.*, 2022).

Our research highlights the possibility of a dual-purpose approach where microalgae can concurrently address biofuel generation and water purification issues. For instance, the nutrient-rich environments of Rimaye and Sabon Gari ponds foster microalgal growth, which can be collected for biofuel while enhancing water quality. Furthermore, combining biofuel production with wastewater treatment can reduce expenses, as demonstrated by the use of Scenedesmus for industrial effluent treatment and biodiesel production in South Africa (Cowan *et al*., 2016; Mehariya *et al*., 2021).

Moreover, a key discovery of the study is the beginning of eutrophication in both ponds, evidenced by the occurrence of *Microcystis* and *Oscillatoria* species, along with reduced dissolved oxygen levels (9.19 ± 0.64 in Sabon Gari and 11.17±0.88 in Rimaye) (Onianwah and Stanley, 2018). This condition poses a risk to fish populations in these ponds, highlighting the necessity for management tactics to combat eutrophication and preserve ecological equilibrium (Fernandes *et al*., 2012; Odulate *et al*., 2017; Sinclair *et al*., 2023). The water quality assessment provided further insight into the ponds' environmental health. While nitrate and phosphate concentrations support microalgal growth, they must be carefully monitored to prevent further eutrophication. Additionally, the detection of zinc and copper within WHO-approved limits is encouraging, as these metals are vital for aquatic life in trace amounts. The lack of lead in both ponds is reassuring, suggesting that water quality is not compromised by this toxic metal, which is often a concern in aquatic ecosystems.

CONCLUSION

This research identified unique microalgal communities and physicochemical properties in the fish ponds of Sabon Gari and Rimaye, located in Nasarawa State, Nigeria. In Sabon Gari, the microalgae included *Chlorella* sp., *Microcystis* sp., *Scenedesmus* sp., and *Coelastrum* sp., whereas Rimaye contained *Euglena* sp., *Chlamydomonas* sp., *Oscillatoria* sp., *Scenedesmus* sp., and *Chlorella* sp. These species belong to major taxonomic groups such as Chlorophyta, Cyanobacteria, and Euglenophyta, highlighting the ecological diversity and biotechnological promise of these ponds. There were significant differences ($p < 0.05$) in crucial water quality metrics, such as pH, dissolved oxygen, BOD, COD, turbidity, hardness, and chloride ions. Sabon Gari exhibited a higher nutrient load and lower oxygen levels, suggesting early signs of eutrophication, as indicated by the presence of *Microcystis* and *Oscillatoria* species. In contrast, Rimaye showed relatively superior water quality, with higher dissolved oxygen levels (11.17 mg/L) and more balanced nutrient levels. Principal Component Analysis indicated strong associations between certain physicochemical parameters and the distribution of microalgal species. In Rimaye, nitrate and dissolved oxygen were positively associated with *Oscillatoria* sp., *Euglena* sp., *Chlamydomonas* sp., and *Chlorella* sp., while in Sabon Gari, chloride ions and BOD were favourable for *Microcystis* sp., *Scenedesmus* sp., and *Coelastrum* sp. Notably, all heavy metal concentrations were within WHO guidelines, affirming the ponds' suitability for aquaculture. The identified microalgae, particularly *Chlorella* sp., *Scenedesmus* sp., and *Euglena* sp., exhibit significant potential for biofuel production and water treatment applications. Ongoing monitoring and nutrient management are crucial for maintaining ecological balance and sustainable resource utilisation.

Recommendations

i. This research highlights the importance of ongoing monitoring and management of fish ponds to maintain ecological balance and optimize the economic benefits of aquaculture.
ii. The identified microalgae offer promising avenues for future biotechnological applications, which could contribute to the sustainable development of the region.
iii. Harnessing *Chlorella sp*, *Scenedesmus sp*, and *Euglena sp* for biofuel production and water treatment is highly feasible, given their nutrient uptake efficiency and lipid-producing capabilities.
iv. *Microcystis sp* and *Oscillatoria sp* pose challenges due to potential toxicity, they can be leveraged under controlled conditions.
v. Continued research and the implementation of nutrient management strategies will be essential to mitigating eutrophication risks and harnessing the full potential of these valuable aquatic resources.
vi. To maximize feasibility, further studies on optimizing growth conditions, reducing production costs, and scaling up are essential. These applications hold promise for sustainable aquaculture management and environmental remediation.

Author contributions

Conceptualization: SAS, ARS
Experimentation and data collection: SAS, ARS
Data analysis: SAS, RAO
Interpretation of findings: SAS, ARS, YAG, OAN, OS, RAO

Writing and revision of manuscript: SAS, YAG, OAN, OS

Declaration of competing interests

The authors confirm that they have no known financial interests or personal associations that may potentially impact the conclusions or analysis of the findings presented in this study.

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