

Bioactive Metabolite Profiling and Broad-Spectrum Antimicrobial Activity of Marine *Anabaena* spp.: A GC–MS-Based Study

reham gamal

reham_niof@yahoo.com

National Institute of Oceanography and Fisheries

Ahmed Ismail

Fayoum University

Article

Keywords: *Anabaena* spp., Marine cyanobacteria, Antimicrobial activity, GC–MS, Bioactive metabolites, Natural products

Posted Date: September 11th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10818193/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: No competing interests reported.

Abstract

Marine cyanobacteria have emerged as promising sources of structurally diverse bioactive metabolites with significant pharmaceutical potential. The present study aimed to evaluate the antimicrobial activity of the methanolic extract of marine *Anabaena* spp. and to characterize its bioactive constituents using gas chromatography–mass spectrometry (GC–MS). The cyanobacterial strain was isolated from the Mediterranean Sea, Egypt, cultivated in F/2 medium under controlled laboratory conditions, and extracted with methanol. Antimicrobial activity was assessed using the disc diffusion method against six bacterial pathogens (*Staphylococcus aureus*, *Enterococcus faecalis*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Aeromonas hydrophila*, and *Vibrio cholerae*) and the fungal pathogen *Candida albicans*. GC–MS analysis was subsequently performed to identify the major metabolites present in the extract. The methanolic extract exhibited broad-spectrum antimicrobial activity against all tested microorganisms. The highest inhibition zone was observed against *Staphylococcus aureus* (19 ± 0.3 mm), followed by *Enterococcus faecalis* (16 ± 0.3 mm) and *Escherichia coli* (15 ± 0.2 mm), while moderate inhibitory effects were recorded against the remaining bacterial species and *Candida albicans*. GC–MS analysis identified twenty metabolites, predominantly fatty acids and their derivatives. The major constituents included hexadecanedioic acid (12.86%), 9,12-octadecadienoic acid (7.56%), 7-hexadecenal (6.80%), octadecanoic acid methyl ester (6.22%), and 9-octadecenoic acid methyl ester (3.88%). These lipid-derived compounds are known to possess antimicrobial properties and are likely responsible for the observed biological activity through synergistic interactions. The findings demonstrate that marine *Anabaena* spp. is a valuable natural source of antimicrobial metabolites and highlight its potential for the development of environmentally sustainable bioactive products for pharmaceutical and biotechnological applications. Further investigations involving compound purification, minimum inhibitory concentration determination, toxicity assessment, and in vivo validation are recommended to confirm its therapeutic potential.

Introduction

The rapid emergence of antimicrobial resistance (AMR) has become one of the most serious global public health challenges, limiting the effectiveness of conventional antibiotics and increasing the burden of infectious diseases. According to the World Health Organization, the continuous rise of multidrug-resistant microorganisms necessitates the discovery of novel antimicrobial agents from sustainable natural resources (Ayswaria et al., 2023). Among these resources, cyanobacteria have attracted considerable attention owing to their remarkable metabolic diversity and their ability to produce a broad spectrum of biologically active secondary metabolites with pharmaceutical potential. Marine cyanobacteria are photosynthetic prokaryotes that inhabit diverse aquatic environments and synthesize numerous bioactive compounds, including fatty acids, peptides, alkaloids, phenolics, terpenoids, polysaccharides, pigments, and lipopeptides (Saee et al., 2022). These metabolites exhibit a wide range of biological activities such as antimicrobial, antioxidant, anti-inflammatory, antiviral, anticancer, and antibiofilm properties. Owing to these characteristics, cyanobacteria are increasingly recognized as promising renewable resources for the discovery of new therapeutic agents and functional biomolecules

(Cock and Cheesman, 2023; Tan and Salleh, 2024). Among filamentous cyanobacteria, *Anabaena* spp. represents one of the most biotechnologically important genera because of their ability to fix atmospheric nitrogen and produce structurally diverse secondary metabolites (Tan, 2013). Previous investigations have demonstrated that *Anabaena* species synthesize numerous bioactive molecules, including fatty acids, phenolic compounds, peptides, and volatile organic compounds that exhibit potent antimicrobial activity against a wide range of Gram-positive bacteria, Gram-negative bacteria, and pathogenic fungi. The production of these metabolites is strongly influenced by environmental conditions, growth phase, and cultivation strategy, highlighting the importance of optimizing culture conditions for enhanced metabolite production (Kar and Ramrao, 2022). Recent advances in metabolomics have significantly improved the characterization of cyanobacterial metabolites. Gas chromatography–mass spectrometry (GC–MS) is considered one of the most powerful analytical techniques for identifying volatile and semi-volatile compounds in cyanobacterial extracts. The integration of GC–MS analysis with biological assays provides valuable insight into the relationship between chemical composition and biological activity and facilitates the identification of potential antimicrobial compounds for pharmaceutical applications (Ezekiel et al., 2024). Several studies have reported that fatty acids and their derivatives constitute the dominant antimicrobial metabolites in cyanobacteria. Compounds such as hexadecanoic acid, linoleic acid, oleic acid, and their corresponding esters possess membrane-disrupting activity that inhibits microbial growth through alteration of membrane permeability, inhibition of essential metabolic pathways, and induction of oxidative stress. Moreover, synergistic interactions among different classes of metabolites often enhance the antimicrobial efficacy of crude cyanobacterial extracts, making them attractive candidates for natural antimicrobial development (Sabat et al., 2025). Despite the growing interest in cyanobacterial natural products, many marine *Anabaena* isolates remain chemically and biologically underexplored. Therefore, the present study aimed to evaluate the antimicrobial activity of the methanolic extract of marine *Anabaena* spp. against selected pathogenic bacteria and *Candida albicans*, followed by comprehensive GC–MS profiling to identify the major bioactive metabolites responsible for the observed biological activity. The integration of antimicrobial evaluation with chemical characterization provides valuable insight into the pharmaceutical potential of marine *Anabaena* spp. as a sustainable source of novel natural antimicrobial agent

Material and methods

Algal Isolation

Marine water samples were collected from the Mediterranean Sea, Egypt. The collected samples were cultured in sterile F/2 medium according to the standard protocol (Guillard, 1975). The culture medium was sterilized by autoclaving at 121°C for 30 min before inoculation. The cultures were maintained under controlled laboratory conditions at pH 8.0, a temperature of $30 \pm 1^\circ\text{C}$, and a light intensity of approximately 3000 lux with a suitable photoperiod to support algal growth. The isolated cyanobacterial strain was purified by repeated subculturing and identified as *Anabaena* sp. based on its morphological

characteristics using standard taxonomic keys and published descriptions (Cronberg & Annadotter 2006).

Measurements of Algal Growth

As per the procedure outlined by (Strickland & Parsons 1972). measuring the growth of algae using chlorophyll a. Centrifugation at 5000 rpm was applied for 15 mins in order to harvest. By comparing the absorbance at 663 and 645 nm in a 1 cm quartz cell to a blank of 80% aqueous acetone utilizing a spectrophotometer, the pigment concentration in the filtered extract was calculated:

$$\text{Chlorophyll a} = 12.7 \cdot E^{663} - 2.69 \cdot E^{645}$$

Preparation of the Algal Extracts

Dried algal sample (approximately 1g each) was individually processed by homogenization using methanol and sonication (20 mins) with a 400W ultrasonic microtip probe (ULTRASONIC Get 750). The mixtures were subsequently centrifuged (4500 rpm) for 10 minutes, and the supernatants were gathered while the remaining pellets were re-extracted two-times using the same method. All collected supernatants were combined and kept in the refrigerator for further analysis. A rotary evaporator was used to evaporate portions of the supernatants to dryness at 40°C; after which the resulting dried extracts were stored within sterile vials at -20°C to be used later in the antimicrobial assays (Chauhan et al., 2010).

Antimicrobial activity assay

The bioactivity of the methanolic crude algal extract was evaluated using the Kirby–Bauer disc diffusion technique against four gram negative bacteria "*Aeromonas hydrophila*, *Pseudomonas aeruginosa*, *Escherichia coli* and *Vibrio cholerae*"; two gram positive bacteria "*Enterococcus faecalis* and *Staphylococcus aureus*" and one fungal species "*Candida albicans*" (Marrez et al., 2017). Bacterial suspensions (150 CFU/ml) were uniformly spread on nutrient agar plates using sterile cotton swabs, whereas fungal spores (0.75×10^6 spores/ml) were aseptically inoculated onto Czapek-Dox agar. The algal extract (10 mg/ml) was impregnated on sterile Whatman No. 1 filter paper discs (6 mm), dried in sterile conditions, and then added on the inoculated media. The plates underwent incubation at 28°C for 48-72hr for fungal and, at 37°C for 24 hr for bacterial species. Positive and negative controls consisted of ciprofloxacin (10 mg/ml) and DMSO, respectively. The antimicrobial potential was assessed via recording the clear zone diameter including the paper disc diameter (mm). All assayed antimicrobial data obtained from triplicate experiments.

GC-MS analysis of methanolic extract from *Anabaena* spp.:

The identification of bioactive compounds present in the methanolic extracts was accomplished utilizing a GC–ISQ mass spectrometer (Thermo Scientific, Austin, TX, USA). Analysis was accomplished with a capillary column TG–5MS (30 m x 0.25 mm x 0.25 µm film thickness). The column oven temperature was first fixed at 55°C and then raised (at 5°C /min) to 250°C and held for 2 mins before being raised (at 25°C/min) to 300°C. The injector temperature was maintained at 270°C. Helium (at 1 ml/min fixed flow rate) served as a carrier gas. The samples (1 µl) were automatically injected through an AS3000 autosampler in split mode with a solvent delay of 4 mins. EI mass spectra were acquired at 70 eV ionization voltages in full scan mode over m/z 50–650 range. The components were identified comparing their mass spectral patterns and retention times with mass spectral database of WILEY 09 and NIST14 (Brondz 2016).

Statistical analysis

Clarify which parameters were analyzed by one-way ANOVA and the statistical software used. State the significance threshold (e.g., $p < 0.05$), and whether post-hoc tests were applied (Duncan 1957).

Results and discussion

Growth of *Anabaena* spp.

The growth of *Anabaena* spp. was monitored by measuring chlorophyll a concentration under controlled culture conditions. The cyanobacterial culture exhibited a typical sigmoidal growth pattern, reaching its maximum biomass on the twelfth day of cultivation (Fig. 1). This stage corresponds to the late exponential phase, during which cyanobacteria actively synthesize secondary metabolites with biological functions. Previous studies have demonstrated that metabolite production in *Anabaena* is highly dependent on growth phase and environmental conditions, with maximum accumulation generally occurring during the late exponential and early stationary phases (Kar and Ramrao, 2022).

Antimicrobial activity

The methanolic extract of marine *Anabaena* spp. exhibited broad-spectrum antimicrobial activity against all tested microorganisms (Table 1). The highest inhibition zone was observed against *Staphylococcus aureus* (19.0 ± 0.3 mm), followed by *Enterococcus faecalis* (16.0 ± 0.3 mm) and *Escherichia coli* (15.0 ± 0.2 mm). Moderate antimicrobial activity was also recorded against *Pseudomonas aeruginosa*, *Aeromonas hydrophila*, *Vibrio cholerae*, and *Candida albicans*. The greater susceptibility of Gram-positive bacteria can be attributed to their relatively simple peptidoglycan cell wall, which allows easier penetration of antimicrobial metabolites (Demay, et al., 2019). Nevertheless, the inhibition observed against Gram-negative bacteria indicates that the extract contains lipophilic compounds capable of interacting with the outer membrane and disturbing membrane integrity. Similar antimicrobial activities have been reported for methanolic extracts of *Anabaena* species, which contain fatty acids, phenolics, peptides, and volatile metabolites capable of disrupting microbial membranes and inhibiting essential

metabolic pathways (Cock and Cheesman, 2023; Tan and Salleh, 2024). Recent studies have shown that cyanobacterial metabolites inhibit microbial growth through several mechanisms, including membrane disruption, inhibition of protein and nucleic acid synthesis, induction of oxidative stress, and interference with quorum sensing and biofilm formation (Kar and Ramrao, 2022). Therefore, the antimicrobial activity observed in the present study is likely due to synergistic interactions among several classes of secondary metabolites rather than a single active compound (Behzadnia A, et al., 2024 ; Al Naim &El Semary. 2022).

Table 1

Antimicrobial activity of the algal methanolic extract against various pathogenic microorganisms.

Inhibition Zone Diameter (mm)							
Standard antibiotics	Gram (+ V) bacteria		Gram (-V) bacteria				Fungal sp.
	<i>S. aureus</i>	<i>E. faecalis</i>	<i>P. aeruginos]</i>	<i>A. hydrophila</i>	<i>V. cholera</i>	<i>E. coli</i>	<i>C. albicans</i>
Ciprofloxacin (+ ve)	20 ± 0.01	22 ± 0.02	22 ± 0.02	22 ± 0.02	22 ± 0.02	22 ± 0.02	20 ± 0.01
DMSO (-v)	-	-	-	-	-	-	-
Anabaena spp.	19 ± 0.3	16 ± 0.3	13 ± 0.2	12 ± 0.2	12 ± 0.2	15 ± 0.2	11 ± 0.2

GC–MS Analysis of the Methanolic Extract of Anabaena spp.

Gas chromatography–mass spectrometry (GC–MS) analysis of the methanolic extract of the marine *Anabaena spp.* revealed the presence of twenty bioactive compounds with different chemical classes, including fatty acids, fatty acid methyl and ethyl esters, aldehydes, alcohols, glycerides, and dicarboxylic acids (Table 2). The detected metabolites were identified based on their retention times and mass spectral comparison with the NIST14 and WILEY09 libraries (Desbois & Smith 2010).). The relative abundance of each compound was estimated from the peak area percentages (Fig. 2). Among the identified metabolites, hexadecanedioic acid was the predominant compound, representing 12.86% of the total chromatographic area at a retention time of 36.28 min. The second most abundant constituent was 9,12-octadecadienoic acid (linoleic acid) with an area percentage of 7.56% at 35.69 min, followed by 7-hexadecenal (6.80%, RT 56.90 min) and octadecanoic acid, methyl ester (6.22%, RT 28.05 min). Other major metabolites included 9-octadecenoic acid (Z)-, methyl ester (3.88%), hexadecanoic acid, 2,3-dihydroxypropyl ester (2.84%), hexadecanoic acid, methyl ester (2.61%), and behenic acid (2.58%). Several additional lipid-derived metabolites were detected at lower abundances, including 9-octadecenoic acid (Z)-, 2,3-dihydroxypropyl ester (1.58%), 2-tetradecanol (1.18%), tripalmitin (1.17%), 5-dodecanol acetate (1.08%), oleic acid (0.95%), ethyl oleate (0.83%), hexadecanoic acid, ethyl ester (0.83%), linoleic acid ethyl ester (0.79%), octadecanedioic acid (0.71%), glycerol 1-palmitate (0.59%), n-hexadecanoic acid (0.55%), and octadecanoic acid (0.54%). Overall, the GC–MS profile demonstrated

that the methanolic extract of marine *Anabaena* spp. was dominated by long-chain fatty acids and their derivatives, indicating that lipid-based metabolites constitute the major chemical constituents of the extract (Sabat S, et al., 2025). The predominance of these compounds suggests that they are likely responsible for the biological activities observed in the present study) Tan and Salleh, 2024; Weiss et al., 2025).

Table 2
Chemical constituents identified by GC–MS in the methanolic extract of *Anabaena* sp.

No.	Retention Time	Area (%)	Peak Name	Formula	Mol. Wt.
1	23.15	2.61	Hexadecanoic acid, methyl ester	C17H34O2	270
2	27.33	1.58	9-Octadecenoic acid (Z)-,2,3 dihydroxypropyl ester	C21H40O4	356
3	28.05	6.22	Octadecanoic acid, methyl ester	C19H38O2	298
4	30.40	0.83	Ethyl Oleate	C20H38O2	310
5	30.73	0.55	n-Hexadecanoic acid	C16H32O2	256
6	31.01	2.84	Hexadecanoic acid, 2,3-dihydroxypropyl ester	C19H38O4	330
7	32.69	0.54	Octadecanoic acid	C18H36O2	284
8	34.73	3.88	9-Octadecenoic acid (Z)-, methyl ester	C19H36O2	296
9	35.69	7.56	9,12-Octadecadienoic acid	C18H32O2	280
10	35.94	0.83	Hexadecanoic acid, ethyl ester	C18H36O2	284
11	36.28	12.86	Hexadecanedioic acid	C16H30O4	286
12	36.53	1.18	2-Tetradecanol	C14H30O	214
13	40.17	0.95	Oleic acid	C18H34O2	282
14	47.77	0.71	Octadecanedioic acid	C18H34O4	314
15	49.70	1.08	5-Dodecanol acetate	C14H28O2	228
16	52.72	2.58	Behenic acid	C22H44O2	340
17	56.65	0.59	Glycerol 1-palmitate	C19H38O4	330
18	56.90	6.80	7-Hexadecenal	C16H30O	238
19	58.82	0.79	Linoleic acid ethyl ester	C20H36O2	308
20	60.27	1.17	Tripalmitin	C51H98O6	806

Relationship between GC–MS Profile and Antimicrobial Activity

The antimicrobial activity observed for the methanolic extract of *Anabaena sp.* can be attributed to the synergistic action of several bioactive compounds identified by GC–MS analysis rather than to a single constituent (El-Seedi et al., 2023). The extract was particularly rich in saturated and unsaturated fatty acids and their derivatives, which are well known for their antimicrobial properties. Among the identified metabolites, hexadecanoic acid (palmitic acid) and hexadecanoic acid methyl ester are widely recognized as antibacterial compounds capable of disrupting microbial cell membranes, increasing membrane permeability, and ultimately causing leakage of intracellular components (Perera, et al., 2023). Similarly, oleic acid and 9,12-octadecadienoic acid (linoleic acid) have been extensively reported to inhibit the growth of both Gram-positive and Gram-negative bacteria through membrane destabilization and interference with essential metabolic pathways (Polyak & Sukharevich 2023). These compounds likely contributed substantially to the inhibitory activity observed in the present study. The detection of octadecanoic acid (stearic acid) and its methyl ester may also have enhanced the antimicrobial effect. Although stearic acid alone generally exhibits weaker antibacterial activity than unsaturated fatty acids, previous studies suggest that it can act synergistically with other lipid-derived metabolites, increasing the overall efficacy of crude algal extracts (Abed 2009). Additionally, 7-hexadecenal may contribute to antimicrobial activity because long-chain aldehydes are known to react with microbial proteins and membrane components, thereby inhibiting microbial growth. Minor constituents such as glycerol monopalmitate, behenic acid, and tripalmitin may further enhance antimicrobial activity through additive or synergistic effects (Desbois & Smith 2010). Therefore, the antimicrobial activity of the methanolic extract of *Anabaena sp.* is likely associated with the combined action of multiple lipid-derived metabolites identified by GC–MS, particularly palmitic acid, oleic acid, linoleic acid, stearic acid, and their esters. Such synergistic interactions are commonly reported in cyanobacterial extracts and explain why crude extracts frequently exhibit stronger antimicrobial activity than isolated individual compounds (Yoon et al., 2018). Overall, the GC–MS profile strongly supports the biological activity observed in the antimicrobial assay and confirms that *Anabaena sp.* represents a promising natural source of antimicrobial metabolites with potential pharmaceutical and biotechnological applications (Singh et al., 2024).

Conclusion

The present study demonstrates that marine *Anabaena spp.* constitutes a promising source of natural bioactive compounds with significant broad-spectrum antimicrobial activity. The methanolic extract exhibited inhibitory effects against all tested bacterial and fungal pathogens, with the highest activity recorded against *Staphylococcus aureus*, highlighting its potential as an alternative source of antimicrobial agents. GC–MS analysis revealed a chemically diverse metabolite profile dominated by fatty acids, fatty acid esters, aldehydes, alcohols, and glycerides. The predominance of hexadecanedioic acid, together with other bioactive lipid-derived compounds such as linoleic acid derivatives and long-

chain aldehydes, provides a plausible explanation for the observed antimicrobial activity. The synergistic action of these metabolites is likely responsible for the broad-spectrum inhibitory effects demonstrated by the crude methanolic extract. The integration of antimicrobial bioassays with GC–MS metabolite profiling provides a comprehensive evaluation of the pharmaceutical potential of marine *Anabaena* spp. and highlights its value as a sustainable source of naturally occurring antimicrobial metabolites. These findings contribute to the growing body of evidence supporting the exploitation of marine cyanobacteria for the discovery of novel bioactive compounds with potential applications in the pharmaceutical, nutraceutical, and cosmetic industries. Nevertheless, further investigations are required to isolate and purify the individual active metabolites, determine their minimum inhibitory and bactericidal concentrations (MIC and MBC), elucidate their mechanisms of action, evaluate their cytotoxicity and safety profiles, and validate their therapeutic efficacy through in vivo studies. Such investigations will be essential for translating the promising biological activity of *Anabaena* spp. into practical biomedical and industrial applications

Declarations

Author contributions

KH and AI contributed to methodology, data collection, original data analysis, and manuscript writing. RG and AI contributed to conceptualization, methodology, data collection, original data analysis, and manuscript writing. All authors have read and agreed to the published version of the manuscript.

Funding

This research received no external funding.

Availability of data and materials

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

Conflicts of interest

The authors declare no conflicts of interest.

References

1. Abed, R. M. M., Dobretsov, S., & Sudesh, K. (2009). Applications of cyanobacteria in biotechnology. *Journal of Applied Microbiology*, 106(1), 1–12. DOI: <https://doi.org/10.1111/j.1365-2672.2008.03918.x>
2. **AI Naim HM, El Semary NA. (2022).** Laser Treatment Increases the Antimicrobial Efficacy of Cyanobacterial Extracts against *Staphylococcus aureus* and MRSA. *International Journal of*

- Environmental Research and Public Health, 19, 13305. <https://doi.org/10.3390/ijerph192013305>
3. Ayswaria, R., Vijayan, J., & Nathan, V. K. (2023). Antimicrobial peptides derived from microalgae for combating antibiotic resistance: Current status and prospects. *Cell Biochemistry and Function*, 41(2), 142–151. DOI: <https://doi.org/10.1002/cbf.3779>
 4. **Behzadnia A, et al. (2024).** Anti-biofilm Activity of Marine Algae-Derived Bioactive Compounds. *Frontiers in Microbiology*, 15. <https://doi.org/10.3389/fmicb.2024.1270174>
 5. **Brondz, I. (2016)** Super Antibiotics, Part II. Hyperforin, Mass Spectroscopy (MS) and Gas Chromatography-Mass Spectrometry (GC-MS), Evidence of Permeability of the Blood-Testis Barrier (BTB) and the Blood-Brain Barrier (BBB) to Hyperforin. *International Journal of Analytical Mass Spectrometry and Chromatography*, 4, 66–73. DOI: 10.4236/ijamsc.2016.44007.
 6. **Chauhan, A.; Chauhan, G.; Gupta, P.; Goyal, P. and Kaushik, P. (2010).** In vitro antibacterial evaluation of *Anabaena* sp. against several clinically significant microflora and HPTLC analysis of its active crude extracts. *Indian Journal of Pharmacy*, 42, 105–107. DOI: 10.4103/0253-7613.64490
 7. **Cock IE, Cheesman MJ. (2023).** A Review of the Antimicrobial Properties of Cyanobacterial Natural Products. *Molecules*, 28(20), 7127. DOI: 10.3390/molecules28207127
 8. **Cronberg, G., Annadotter, H., (2006)** Manual on Aquatic eubacteria. ISSHA; 2: p. 1–106. DOI: 10.17485/ijst/2019/v12i1/134088
 9. **Demay J, et al. (2019).** Natural Products from Cyanobacteria: Focus on Biological Activities. *Marine Drugs*, 17, 320. <https://doi.org/10.3390/md17060320>
 10. **Desbois AP, Smith VJ. (2010).** Antibacterial Free Fatty Acids: Activities, Mechanisms and Biotechnological Potential. *Applied Microbiology and Biotechnology*, 85, 1629–1642. <https://doi.org/10.1007/s00253-009-2355-3>
 11. **Duncan, B. D. (1957).** Multiple range tests for correlated and heteroscedastic means. *Biometrics* 13,359–364. DOI:10.2307/2527799
 12. El-Seedi, H. R., El-Mallah, M. F., Yosri, N., et al. (2023). Review of marine cyanobacteria and the aspects related to their roles: Chemical, biological properties, nitrogen fixation and climate change. *Marine Drugs*, 21(8), 439. DOI: <https://doi.org/10.3390/md21080439>
 13. **Ezekiel A., Olusola N. M., Hakeem B., Adekunle A. (2024).** Phytochemical Screening, GC-MS Study, FTIR analysis and antimicrobial activities of ethanol extracts of *Tetrapleura tetraptera* fruit. *International Journal of Frontiers in Science and Technology Research* 7(2):109–118. DOI: 10.53294/ijfstr.2024.7.2.0060
 14. **Guillard, R. R. L. (1975).** Culture of phytoplankton for feeding marine invertebrates. *Culture of Marine Invertebrate Animals*. New York: Plenum Press; p. 29–60. DOI:10.1007/978-1-4615-8714-9_3
 15. **Kar J, Ramrao DP. (2022).** Revisiting the Role of Cyanobacteria-Derived Metabolites as Antimicrobial Agents. *Frontiers in Microbiology*, 13, 1034471. <https://doi.org/10.3389/fmicb.2022.1034471>
 16. **Marrez, D.A.; El Raey, M.A.; El-Hagrassi, A.M.; Seif, M.M.; Ragab, T.I.; et al. (2017).** Phenolic profile and antimicrobial activity of *Acalyphawilkesiana* seeds silver nanoparticles green synthesis against some food borne pathogens. *Bioscience Research*, 14, 817–830.

17. Perera, R. M. T. D., Herath, K. H. I. N. M., Sanjeewa, K. K. A., & Jayawardena, T. U. (2023). Recent reports on bioactive compounds from marine cyanobacteria in relation to human health applications. *Life*, 13(6), 1411. DOI: <https://doi.org/10.3390/life13061411>
18. Polyak, Y. M., & Sukharevich, V. I. (2023). Problems and prospects of applications of cyanobacteria (Review). *Inland Water Biology*. DOI: <https://doi.org/10.31857/S032096522301014X>
19. **Sabat S, et al. (2025).** Phycocompounds from Cyanobacteria: Exploring Synergistic Effects with Conventional Antimicrobial Properties. *ACS Omega*, 10, 23957–23980. DOI: 10.1021/acsomega.5c03526
20. Saeed, M. U., Hussain, N., Shahbaz, A., Hameed, T., Iqbal, H. M. N., & Bilal, M. (2022). Bioprospecting microalgae and cyanobacteria for biopharmaceutical applications. *Journal of Basic Microbiology*, 62(9), 1110–1124. DOI: <https://doi.org/10.1002/jobm.202100445>
21. **Singh et al. (2024).** Cyanobacterial Bioactive Metabolites: Recent Advances and Biomedical Applications. *Marine Drugs*, 22, 180. <https://doi.org/10.3390/md22040180>
22. **Strickland, J.D.H. and Parsons, T.R. (1972)** A practical handbook of seawater analysis. 2nd Eds. Bull. Fish. Res. Bd. Canada 167, 311pp.
23. **Tan LT-H, Salleh NFM. (2024).** Marine Cyanobacteria: A Rich Source of Structurally Unique Anti-Infectives for Drug Development. *Molecules*, 29(22), 5307. DOI: 10.3390/molecules29225307
24. Tan, L. T. (2013). Pharmaceutical agents from filamentous marine cyanobacteria. *Drug Discovery Today*, 18(17–18), 863–871. DOI: <https://doi.org/10.1016/j.drudis.2013.05.010>
25. **Weiss MB, et al. (2025).** Chemical Diversity of Cyanobacterial Natural Products. *Natural Product Reports*, 42, 6–49. <https://doi.org/10.1039/D4NP00040D>
26. **Yoon BK, et al. (2018).** Antimicrobial Free Fatty Acids and Their Potential Applications as Anti-Infective Agents. *Trends in Food Science & Technology*, 80, 204–216. <https://doi.org/10.1016/j.tifs.2018.08.007>

Figures

Anabaena spp.

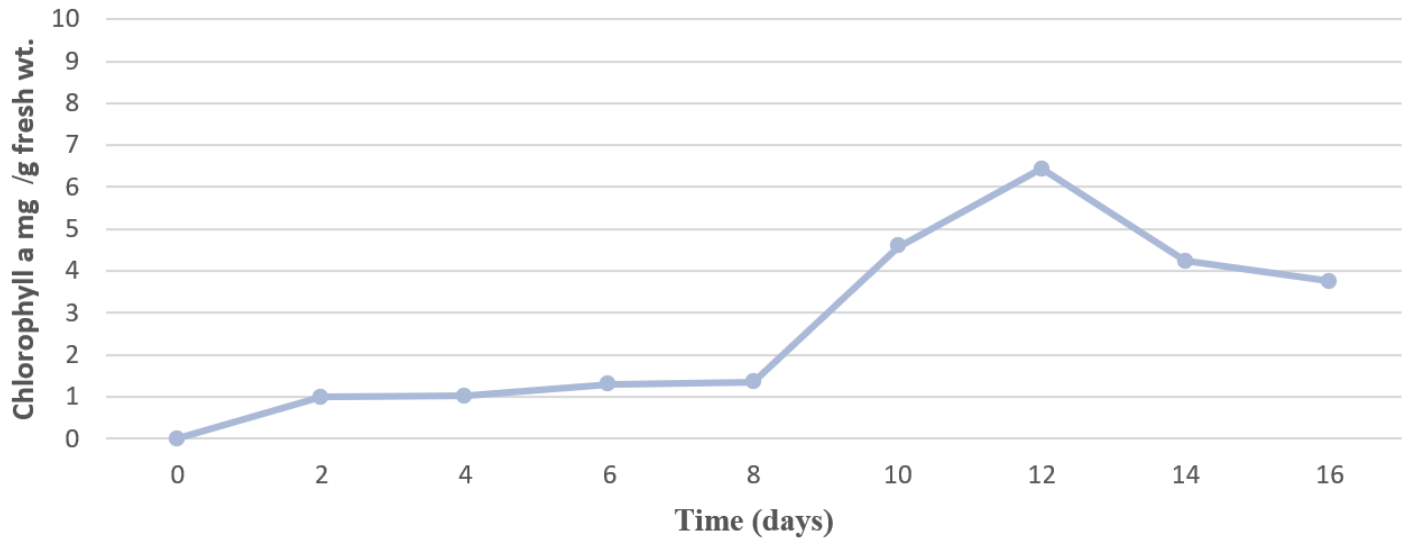


Figure 1

The growth of *Anabaena spp.* measured as chlorophyll (a) mg/g fresh wt.

Anabaena spp.

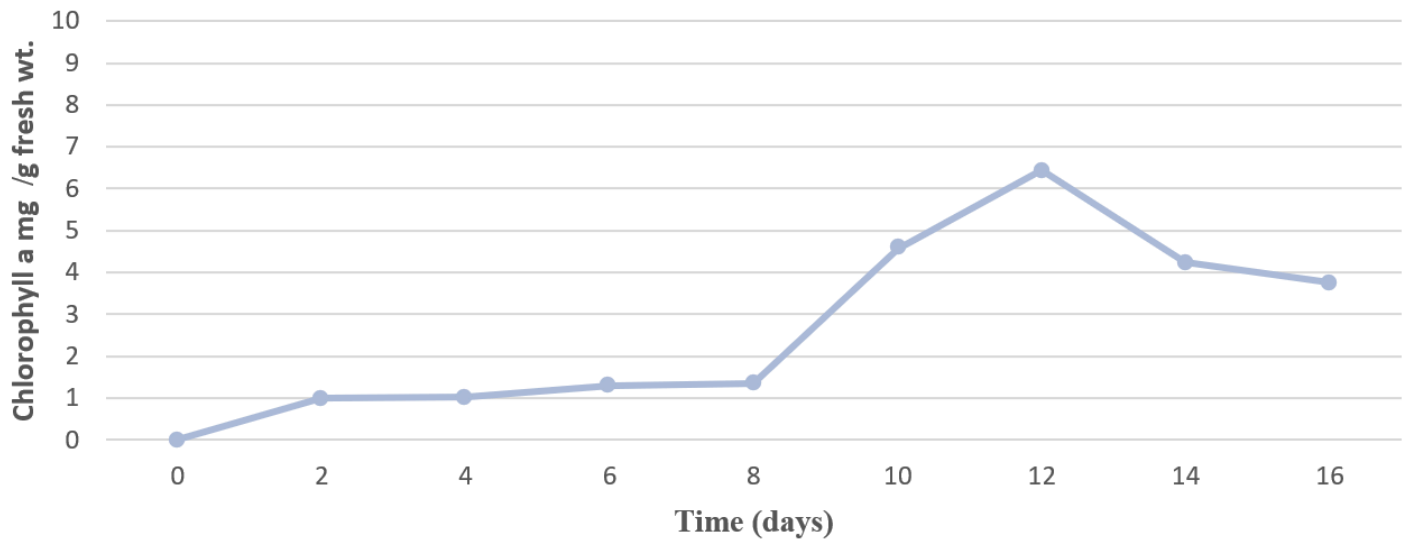


Figure 1

The growth of *Anabaena spp.* measured as chlorophyll (a) mg/g fresh wt.

Anabaena spp.

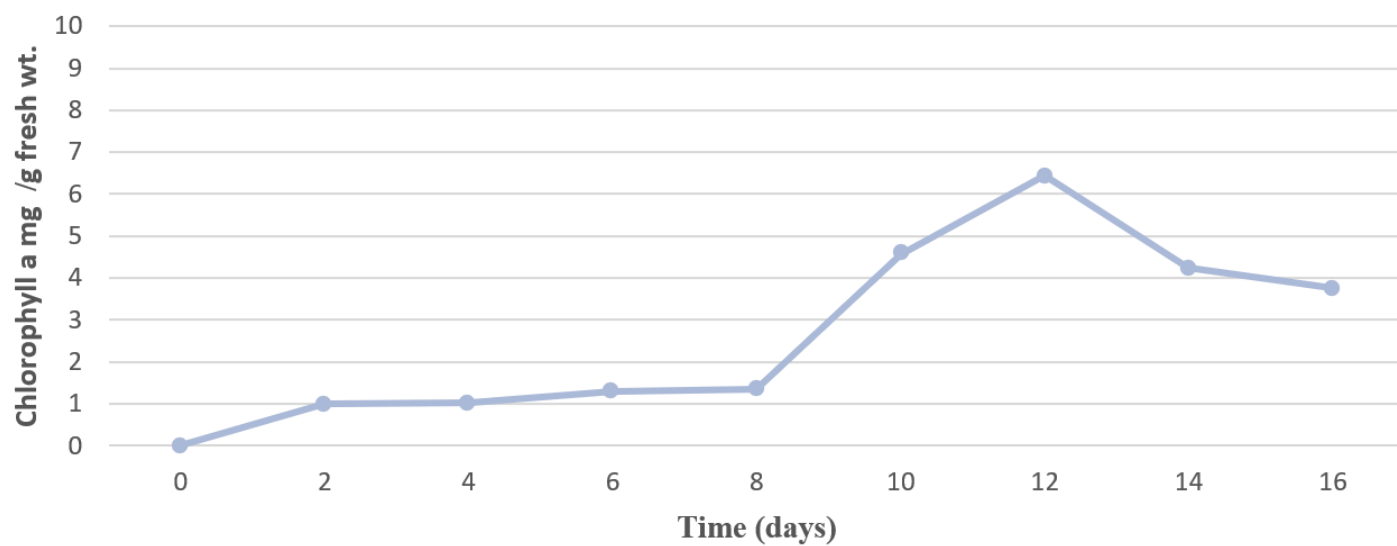


Figure 1

The growth of *Anabaena* spp. measured as chlorophyll (a) mg/g fresh wt.

GC-MS Total Ion Chromatogram (TIC) of Methanolic Extract of *Anabaena* spp.

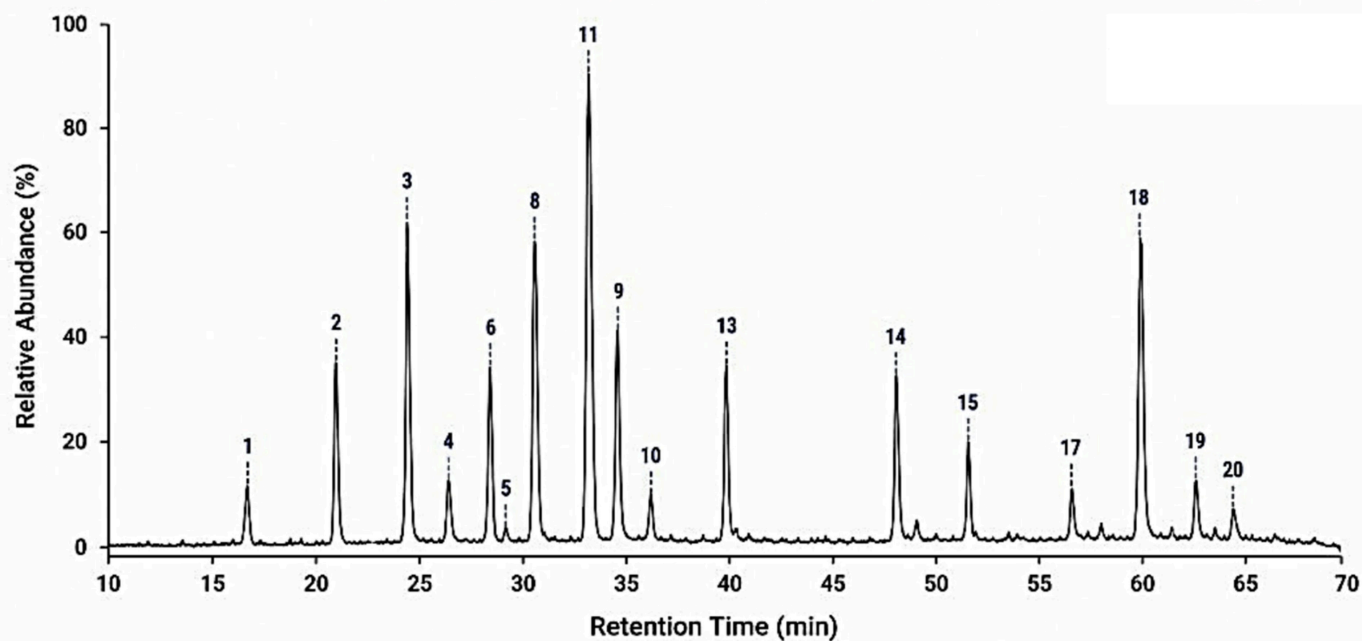


Figure 2

GC–MS chromatographic profile of the methanolic extract of marine *Anabaena spp.*, showing the distribution of the detected bioactive metabolites.

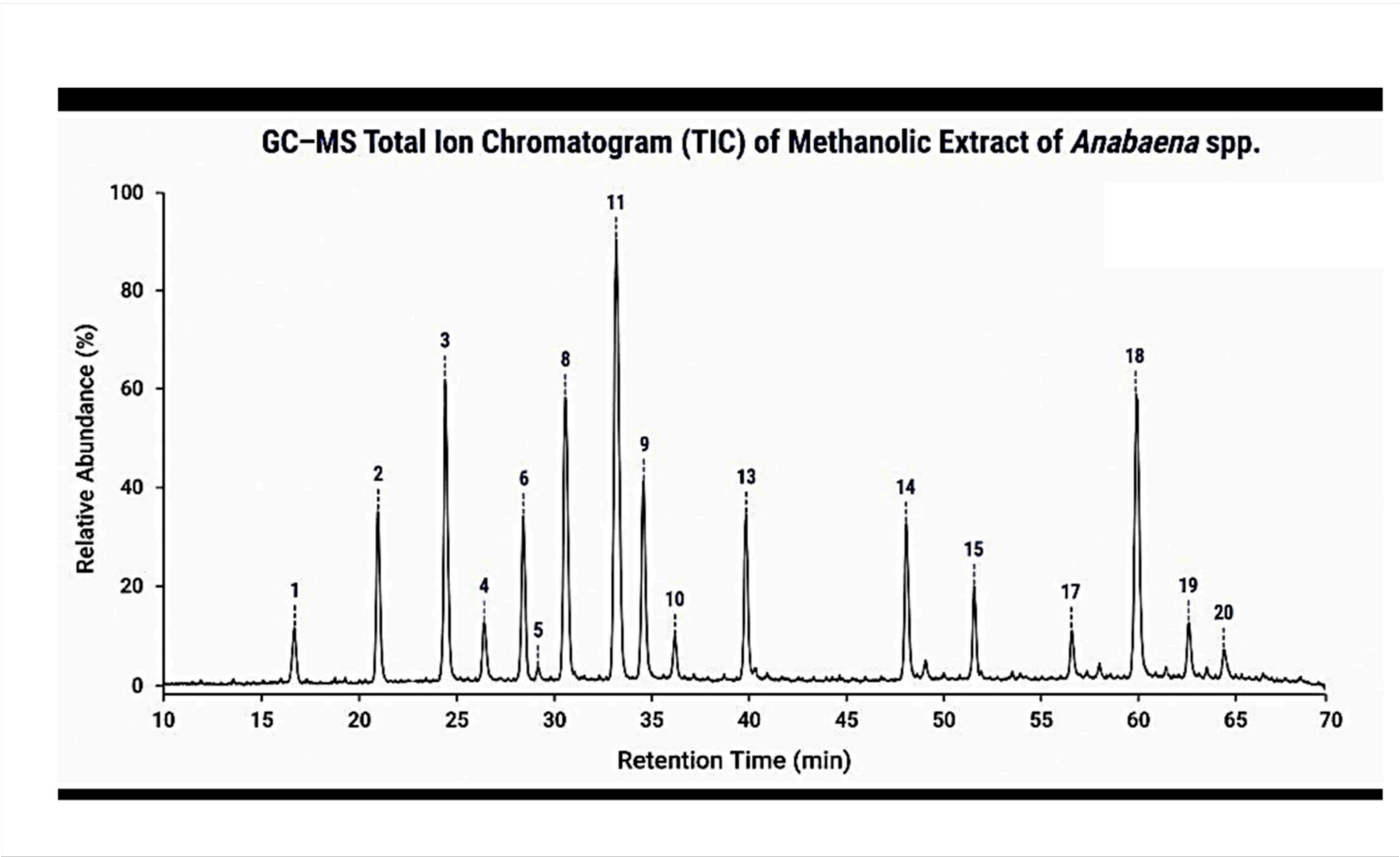


Figure 2

GC–MS chromatographic profile of the methanolic extract of marine *Anabaena spp.*, showing the distribution of the detected bioactive metabolites.

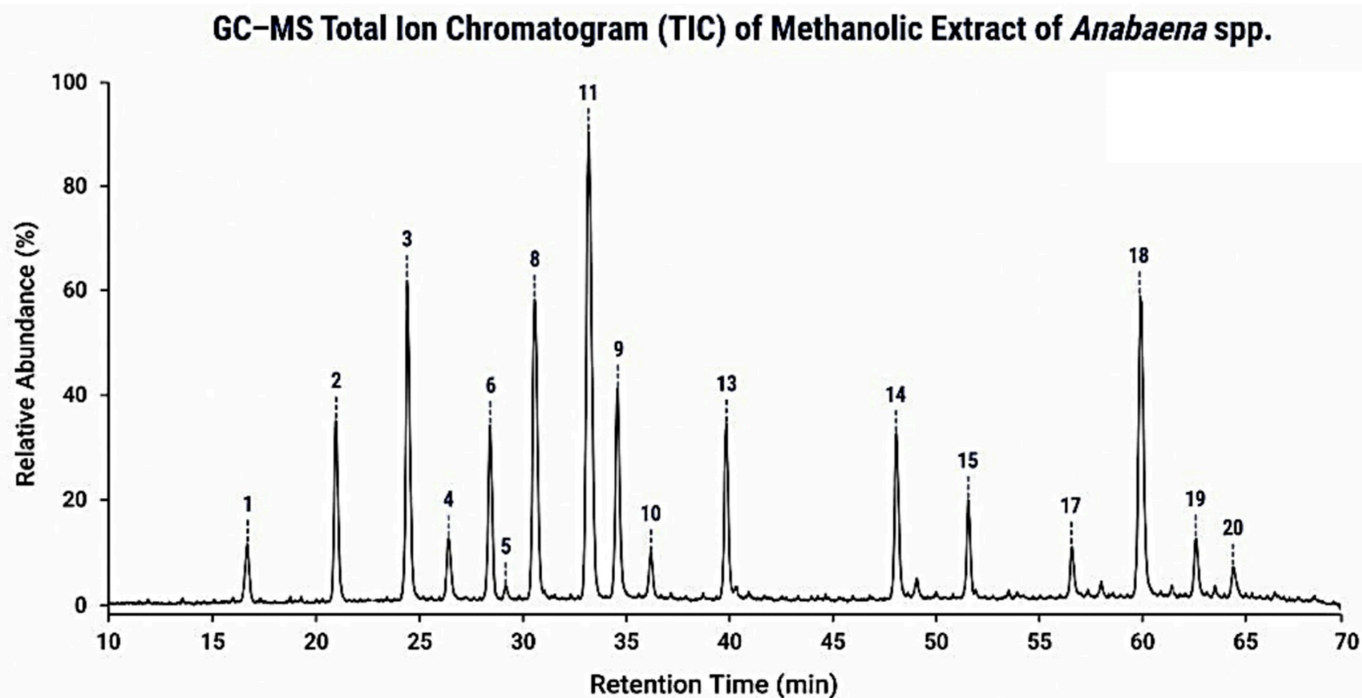


Figure 2

GC-MS chromatographic profile of the methanolic extract of marine *Anabaena* spp., showing the distribution of the detected bioactive metabolites.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [floatimage1.png](#)
- [floatimage1.png](#)
- [floatimage1.png](#)