Plant Life and Environment Dynamics

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Insights into the World of Diatoms: From Essentials to Applications

Springer

About this book

This edited book provides a comprehensive and a reliable source of information on all major areas of diatom research. It addresses research advances in the key areas of diatom biology, morphology, systematics, phylogeny and ecology along with their interdisciplinary applications. Diatoms are the world's most diverse group of algae populating the freshwater and marine ecosystems of the world. They are unicellular, photosynthetic, eukaryotes having ornate silicified cell walls. Diatoms contribute around 25% of annual global carbon fixation, which is more than all of the terrestrial rainforests combined. Diatoms underpin major aquatic food webs and drive global biogeochemical cycles and have several ecological and interdisciplinary applications. This book targets a wide range of audience including researchers, academicians, teachers and students of varied disciplines such as biology, environmental sciences, ecology, evolution, nanotechnology and other related disciplines. It is useful read for beginners as well as advanced researchers.

Keywords

Diatoms | Biogenic Silica | Environmental indicators | Diatom nanobiotechnology | Novel materials | Biofuels | Biogeography | Biomonitoring | Climate change and diatoms

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Foreword

The diatoms are algal forms that are known for creating a castle of glass. They have a unique type of cell wall composed of silica. But for Leeuwenhoek, who devised a model of microscope with 300-fold magnification, it would not have been possible to see these minute organisms and their beautiful ornamentation. These ubiquitous organisms are the major primary producers in all aquatic ecosystems and moist places, and hence form the base of food web on which the higher trophic levels are dependent. They are well-known surrogate for the past climatic events because they settle at the bottom of lakes and oceans after death and remain intact because cell walls are readily preserved well along with their intricate microscopic details owing to their siliceous nature. As consumers of 20–25% of the global CO_2 they are important for the study of present climate.

Of recent, the science around diatoms has been concentrated mostly in Europe, Russia, North America, and Japan. As more and more samples were examined the workers left reference slides, material and publications as a record of their work. These are preserved in museums and institutions around the world. Major collections from the nineteenth century can be found in Philadelphia, Vienna, Berlin, Antwerp, Stockholm, Edinburgh and London. Diatom flora and taxonomy has been the major area of interest In India. Other perspectives have received scarce attention.

The initiative Diatoms: Biology and Applications is indeed an effort to generate interest in this less explored organism. This volume contains valuable information on the fundamentals of diatom biology and its multifarious applications to current as well as general issues. The included chapters throw a panoramic view of the world of diatoms touching upon biological aspects such as pigment composition and ecological and environmental facets such as climate change, ocean acidification and impact assessments. The book also takes into account varied applications of diatom research prevalent around the world such as nanobiotechnological utilization and forensic applications. I congratulate the editors for their collective wisdom in selecting a suitable theme for this volume. The information emerging from this volume will create interest in the young minds pursuing research as a career in national and international research institutes, universities and colleges. It will also attract research

laboratories looking for fresh areas of research or unique organism models. It will be equally handy for planners, policymakers and managers of water for domestic and industrial use, be it rivers, lakes, lagoons and reservoirs.

I am quite convinced that the effort will spark and ignite minds when it reaches the bookshelves and e-books of individuals and libraries. It is a beginning to reach out and probe the scientific minds.

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Prakash Nautiyal

Preface: The World of Diatoms

We often come across partially or completely submerged rocks in streams and rivers covered by golden brown slimy films. These biofilms are composed of microscopic eukaryotic organisms commonly known as the diatoms. These wonderful organisms though are not only restricted to streams and rivers but are abundant in most aquatic ecosystems such as lakes, ponds, wetlands, oceans and even in soils with adequate moisture content.

The word diatom comes from the Greek dia, meaning "through", and temnein, implying "to cut", literally meaning "cut in half", as they consist of two overlapping and interlocking units of their frustules. Diatoms are eukaryotic, unicellular and autotrophic organisms which are characterized by unique cell walls made up of silica (hydrated silicon dioxide). The frustules of diatoms are intricately sculptured and ornate. It is due to their enchanting beauty of their cell walls that these organisms have been labelled as "jewels of the sea". They have been systematically placed in the stramenopile clade of the SAR supergroup and are recognized as members of Bacillariophyceae or Bacillariophyta.

The chloroplasts of diatoms contain chlorophylls a and c along with carotenoids such as fucoxanthin: the pigment responsible for the characteristic golden brown colour. These tiny organisms are the major component of the phytoplankton communities of the oceans and constitute approximately half of the organic material found in the oceans. They are responsible for the production of roughly 25–30% of oxygen globally which equals the contribution of the rainforests combined. They are known to be more energy efficient than their counterparts with organic cell walls. Moreover marine diatoms essentially sequester considerable amount of carbon dioxide from the atmosphere.

Fossil evidences trace back the origin of diatoms to early Jurassic Period though molecular clocks indicate the appearance of diatoms to Triassic period. The emergence of diatoms caused a major shift in the ocean carbon cycle with increased carbon locking in dead diatom cells. Genome sequencing of diatoms such as *Thalassiosira pseudonana* and *Phaeodactylum tricornutum* has thrown light on the unique secondary endosymbiotic origin of diatoms. These genomic studies

also revealed several biochemical features of diatoms which are similar to that of organisms of the animal kingdom.

Diatoms have been extensively used in the water quality estimation of aquatic ecosystems such as lakes, rivers, wetlands, etc. and also in paleolimnological reconstructions. They are robust ecological monitors and have been used in assessment purposes throughout the world. The Water Framework Directive has recommended the utilization of diatoms in water quality monitoring programmes. The widespread use of diatoms for ecological health assessment of ecosystems has led to the generation of indicator and sensitivity value of several diatom species. Diatom indices are increasingly being used to evaluate the state of aquatic ecosystems. Recently the potential of terrestrial diatoms for ecological monitoring has also been explored.

Commercial applications of diatoms have a long history. Diatomaceous earth, the fossilized remains of diatoms, has been used in explosives, filtration systems, pest control, agriculture, etc. The unique way of deposition of silica by diatoms in their frustules has widespread applications in nanotechnology such as biosensors, bioimaging, drug delivery, etc. Diatoms have been extensively used in forensics and biofuel production.

The domain of diatom research has tremendous potential. From unravelling secrets of evolution to climate change mitigation, insights into the world of diatoms are expected to uncover evolutionary enigmas and enhance their commercial applications.

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Noida, Uttar Pradesh, India — Ambrina Sardar Khan
Prayagraj, Uttar Pradesh, India — Jyoti Verma
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readers for the improvement of our book. Last, but in no way the least, we wish to thank our family members from the core of our hearts for their understanding, patience and support for completion of this enormous task.

Prateek Srivastava
Ambrina Sardar Khan
Jyoti Verma
Shalini Dhyani

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Editors and Contributors

About the Editors

Prateek Srivastava received a PhD in Botany from the University of Allahabad. His research areas are freshwater ecology and phycology. He has been awarded several research projects from reputed funding agencies of India viz. Ministry of Science & Technology, Ministry of Environment and Climate Change and Science and Engineering Research Board, most of which have focused on diatoms and other river algae. Two students have been awarded with the PhD degree under his guidance. He has been teaching ecology, biodiversity and phycology to UG and PG students since 2008. He has worked as an assistant professor in Amity University, Noida, from 2010 to 2017 and is presently working in the Department of Botany, University of Allahabad. He has more than 35 publications to his credit which include research papers in peer-reviewed international and national journals, book chapters, conference proceedings, etc. He has organized and attended several national and international seminars and workshops.

Ambrina Sardar Khan has completed her PhD in Environmental Science from the University of Allahabad in the year 2010. Since then, she has been working as an Assistant Professor in Amity University, Uttar Pradesh, and is engaged in UG and PG teaching. She taught various subjects like Geo-environmental and meteorological Sciences, Environmental Law, audit and policies, Disaster management and planning and Environmental pollution to the students of Master's in Environmental Sciences and M.Tech Environmental Engineering. Her areas of interest are Air and water quality monitoring, ecotoxicology, Nutritional and health risk assessment and Sustainable urban development. She had published two books namely *Disaster Management and Preparedness* with CBS publication and *Health & Environment: Key Factors for Sustainable Urban Development: Changing cities with challenging issues* with Lambert Publication. She is actively engaged in R&D and has published several research papers in various reputed journals.

Jyoti Verma is working as an Assistant Professor, Department of Zoology, CMP PG College, University of Allahabad. She has worked with Indian Institute of Technology, Kanpur, as a Project Scientist in GRBMP, World Bank project, and Biodiversity expert in E-FLOW Project of World Wildlife Fund India supported by HSBC. She has also completed many Environmental Impact assessment reports of Northeastern states. She has completed a research project on diatoms of Indian subcontinent funded by Indian Government Agencies. Presently she is working on a UGC Start-up grant project on Diatom Biodiversity of Ken-Betwa Rivers. She has received UGC-Women PDF Fellowship Award 2011, CSIR-International Travel Fellowship 2012, Young Scientist award in Oral Presentation 2016, International Travel Fellowship DST 2018, Young Indian Diatomist 2018 and Young Environmental Scientist Award 2018 at JNU, New Delhi.

She has published more than 35 publications in peer-reviewed international and national journals, 7 book chapter and 10 reports. She has attended and presented more than 30 research papers in national and international seminars and 12 workshops. She has visited many countries as a recourse person and young researcher (Germany, Thailand, Malaysia and Nepal). She is a member and fellow of many national and international prestigious societies. She is a reviewer and member of the editorial boards of national and international journals. She has supervised a PhD student of Amity University as a Co-Supervisor (awarded) and one student enrolled for PhD under her supervision.

Shalini Dhyani is Senior Scientist with Critical Zone Group of Water Technology and Management Division in CSIR-NEERI, India. She is South Asia Regional Chair for IUCN CEM (Commission on Ecosystems Management) (2017–2020). She is IPBES Lead Author Global thematic assessment on Sustainable Use of Wild Species (2018–2021) and was lead author for IPBES Asia Pacific regional assessment of biodiversity and ecosystem services in Asia Pacific (2015–2018). She did her doctoral work from Forest Research Institute, Dehradun. Presently, she is involved in a multidisciplinary long-term Critical Zone research for understanding the functioning and impact of groundwater-dependent ecosystems and APN-IGES, Japan project on developing plausive alternate scenarios for Bhitar kanika, India. Dr. Shalini has worked on Biodiversity Inclusive impact assessment of important developmental projects across India and has also contributed to many NGT and Judiciary projects. Her work in Upper Ganga catchment focuses on understanding the role of riparian buffers for ensuring river health and role of phytochemicals in giving special property to river water. She has worked in Indo-EU projects on decontamination of soil and water using techno-ecological solutions. She was jury member for innovation prize programme on climate change adaptation (CCA) at scale (A@S) 2019 by IMC, UK, for Nepal. Dr. Shalini was awarded "IUCN-CEM Chair Young Professional Award" at World Parks Congress 2014 in Sydney, Australia, for her excellent research on Himalayan ecosystems. Dr. Shalini is a recipient of various national as well as international financial grants viz. UNEP, UNESCO, GIZ, FAO, IUCN, UNU, European Union-LEANES, Rufford SGP,

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Abbreviations

β-car	β carotene
βTCP	β-tricalcium phosphate
AD	Alzheimer's disease
aDDS	Advanced drug delivery systems
AEAPTMS	3-aminopropyl trimethoxysilane
AMD	Age-related macular degeneration
APTES	3-aminopropyl triethoxysilane
Ax	Antheraxanthin
BQE	Biological quality elements
Chl a	Chlorophyll a
Chl b	Chlorophyll b
Chl c	Chlorophyll c
Chls	Chlorophylls
CWM	Conjunctive water management
Cx	β-cryptoxanthin
CxE	β-cryptoxanthin-epoxide
DD	Diadinoxanthin
Ddx	Diadinoxanthin
DE	Diatomaceous earth
DMAPP	Dimethylallyl diphosphate
DOX	Doxorubicin
DPOR	Dark operated protochlorophyllide oxidoreductase
DSNs	Diatomite silica nanoparticles
Dt	Diatoxanthin
Dtx	Diatoxanthin
FCP	Fucoxanthin-chlorophyll-protein
FTIR	Fourier transform infrared
Fx	Fucoxanthin
GGPP	Geranylgeranyl pyrophosphate
HEP	Hydroelectric projects
hMSCs	Human pluripotent stromal cells

HPQR	High-pressure rapid release
HTL	Hydrothermal liquefaction
HTU	Hydrothermal treatment
IDE/S	Index of Saprobity Eutrophication
IDG	Generic Diatom Index
IPCC	Intergovernmental Panel on Climate Change
IPP	Isopentenyl pyrophosphate
IPS	Specific Pollution Index
LHC	Light harvesting proteins
LPOR	Light operated protochlorophyllide oxidoreductase
LSPR	Localized surface plasmon resonance
MEP	Methylerythritol phosphate
MEV	Mevalonate
MG63	Hypotriploid human cell line
MGNREGS	Mahatma Gandhi National Rural Employment Guarantee Scheme
NPQ	Non-photochemical quenching
NPs	Nanoparticles
Nx	Neoxanthin
PDS	Phytoene desaturase
PEG	Polyethylene glycol
PH	Powerhouse
PL	Photoluminescence
PSY	Phytoene synthase
PTX	Paclitaxel
SDGs	Sustainable Development Goals
SERS	Surface-enhanced Raman spectroscopy
siRNA	Small interfering RNA
SLA	Sustainable Livelihoods Approaches
SPU	Signal processing unit
TDI	Trophic Diatom Index
TEMPO	2,6,6-tetramethylpiperidine-*N*-oxyl
USEPA	U.S. Environmental Protection Agency
VDE	Vx de-epoxidases
VOCs	Volatile organic compounds
Vx	Violaxanthin
WFD	Water Framework Directive
WHO	World Health Organization
ZEP	Zx epoxidases
Zx	Zeaxanthin

Chapter 15
Biofuels from Diatoms: Potential and Challenges

Jyoti Verma, Akriti, Hemlata Pant, and Ambrina Sardar Khan

Abstract Biofuel is the hope of this planet to ensure safe and sustainable use amid increasing rate of pollution and global warming. The term biofuel may be misleading for some that it is only substitute of fossil fuels, which is not true. Biofuel is a broad term including bio-oil, biodiesel, bioethanol, biogas, etc. finding its use in transportation, cosmetics, cooking, nutrient supplements, etc. The generation of biofuel from diatoms is third-generation biofuel production. Either the lipid from diatoms is extracted as bio-oil or the whole biomass of diatoms is used as biocrude. Apart from the mainstream uses of biofuel, the diatom culture produces many by-products which find their use in multiple fields. The public authority of India reported Biofuels Policy in 2008 to advance its production and utilization. The main obstacle on the way is economic production of biofuel from diatoms, to make it worth choosing over other options. Diatoms grow fast but they produce lipids slow, and the process of extraction is even more tedious. However, with the use of recent technologies, proper management and planning, this method proves to be the most efficient and environment friendly way of biofuel production. Diatoms don't have a large number of cells in the body to support, they use carbon dioxide and other nutrients from waste, or eutrophied water bodies produce biofuel and clean their nearby environment in return. It is high time we develop this method to make it feasible for greater good.

Keywords Biofuels · Diatoms · Microalgae · Hydrocracking · Sustainable energy

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15.1 Introduction

Biofuel is a kind of fuel (liquid or gaseous), produced over a short time span from the biotic component of our environment rather than very slow natural processes involved in the formation of fossil fuels. It could be derived from plant, algae material or animal waste. These materials could be replenished readily, making biofuel a source of renewable energy. The word fuel associated with biofuel could lead to assumptions, that it could be used only for transportation purposes. Biofuel's advantage is not limited to one field only but also extended to energy generation, heat production, charging electronics, clean oil spills and grease, lubrication, removal of paint and adhesive, as cooking oil and there are many yet to be discovered to utilize their full potential.

15.1.1 Diatoms

Diatoms, a significant component of phytoplankton, are microalgae. They contain silica-based tiny shell walls. The lineage is traditionally divided into two orders: radially symmetrical centric diatoms, or centrales, and bilaterally symmetrical pennate diatoms, or pennales. The first order is further classified into polar and non-polar centrics, whilst the latter order comprises the classes Bacillariophyceae and Fragilariophyceae based on the presence or absence of a raphe; each group emerged and developed progressively over the Mesozoic era when CO_2 levels decreased. Diatoms displaced a substantial amount of other algae (mostly cynobacteria and few green algae) in the ocean throughout the Mesozoic era, according to the fossil record (Hildebrand et al. 2014). They evolved around the Jurassic Period. They have the ability to biosynthesize a variety of commercially valuable chemicals.

Each year, living diatoms generate 20% to 50% of the oxygen produced on the Earth, absorb about 6.7 billion metric tons of silicon from the waters in which they dwell and account for nearly half of the organic material present in the seas (Treguer 1995). Diatoms are natural nanotechnology factories that have been discovered in the fossil record for over 100 million years. Diatoms are less sensitive to turbulence in the ocean than any other phytoplankton (Wyatt 2014).

Diatoms also produce other useful items such as semiconductors, health foods (glucosamine) and chitin fibres. These incredible microscopic algae will be able to absorb some of the cheapest, most abundant elements on Earth—like silicon and nitrates—and make a steady stream of affordable products with nothing more than sunlight, practically any sort of water and carbon dioxide (Rorrer 2012).