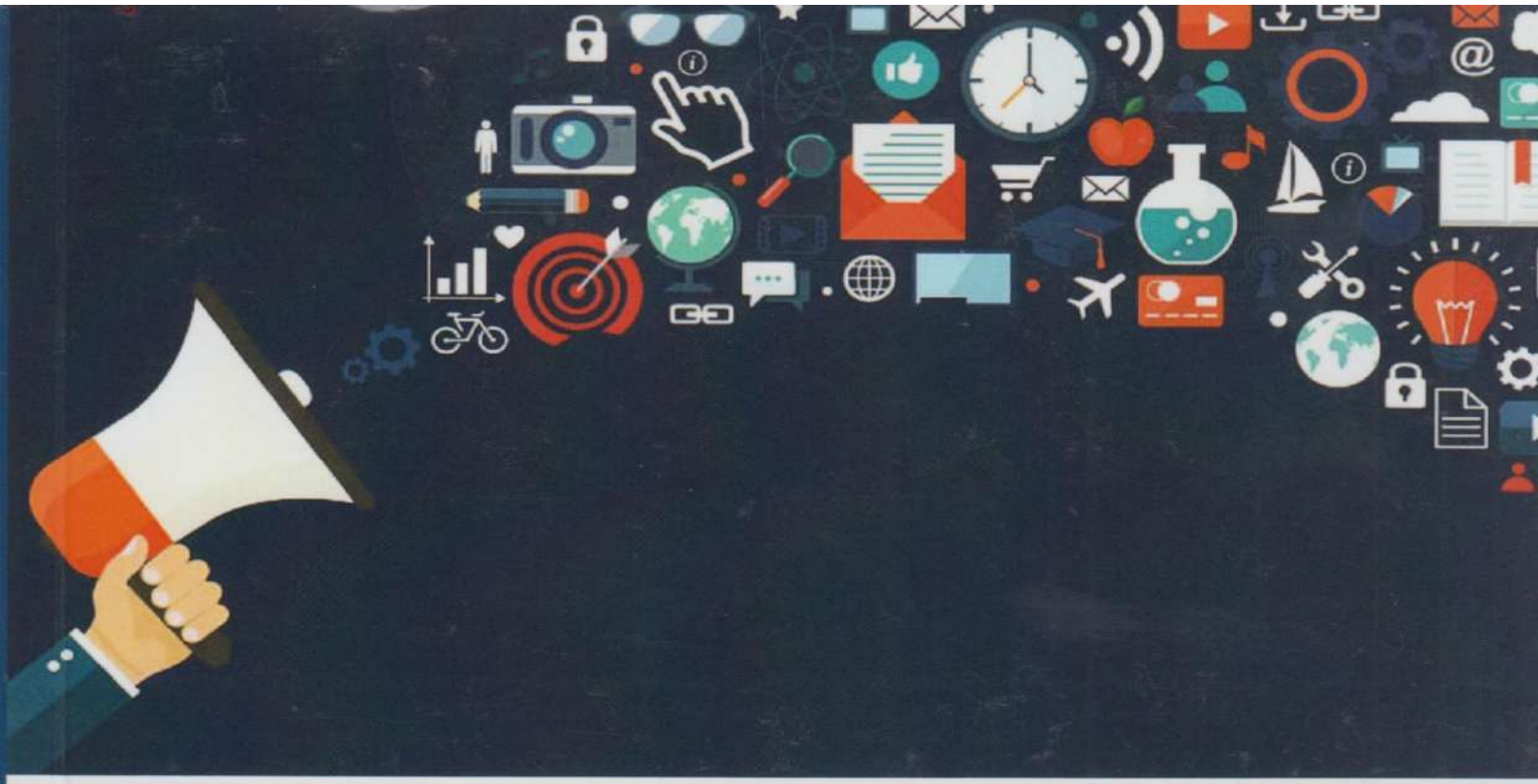


DIGITAL MARKETING

Dr. M. CHANDRA
Dr. L. KALAI BHARATHI



Title of the Book - DIGITAL MARKETING

Edition: First - 2023

Copyrights © Authors

No part of this text book may be reproduced or transmitted in any form by any means, electronic or mechanical, including photocopy, recording, or any information storage and retrieval system, without permission in writing from the copyright owners.

Disclaimer

The authors are solely responsible for the contents published in this text book. The publishers or editors do not take any responsibility for the same in any manner. Errors, if any, are purely unintentional and readers are requested to communicate such errors to the editors or publishers to avoid discrepancies in future.

ISBN: 978-93-5757-570-6
MRP: Rs. 650/-

PUBLISHER & PRINTER: Scientific International Publishing House

Contact: **+917019991025**

Website: **www.sipinternationalpublishers.com**

TABLE OF CONTENTS

Chapter No.	Contents	Page No.
1	**FUNDAMENTALS OF MARKETING**	**01**
	1.1 Introduction	01
	1.2 Fundamentals of Marketing	04
	1.2.1 Internet Marketing Strategy	07
	1.3 The Modern Digital Consumer and New Consumer's Digital Journey	14
	1.3.1 Understanding the Customer's Journey	16
	1.3.2 The New Digital World	18
	1.4 Types of Marketing	21
	1.5 Difference between Traditional Marketing and Digital Marketing	24
	1.6 Difference between Field Marketing and Digital Marketing	26
	1.7 Difference between Social Media Marketing and Digital Marketing	27
	1.8 Domain Names, Webhosting Web Browsers	29
	1.8.1 Website Planning: Strategies and Approaches	31
	1.8.2 Planning Website Design	35
	1.9 Process of Digital Marketing	36
	1.10 Advantages and Disadvantages of Marketing	38
2	**PRACTICAL ASPECTS OF DIGITAL MARKETING**	**43**
	2.1 Introduction	43
	2.1.1 Types of SEO	48
	2.1.2 Local SEO	51
	2.1.3 Black HAT and White HAT SEO	52
	2.1.4 Advantages and Disadvantages of SEO	55
	2.2 Pay-Per-Click	56
	2.3 Social Media Marketing	62
	2.3.1 Social Media Landscape	63
	2.3.2 Best Social Media Marketing Tips	66
	2.3.3 Importance of Social Media Marketing	67
	2.3.4 Social Media Marketing Plan	68
	2.3.5 Tracking Social Media Marketing Performance	71
	2.4 Content Marketing	73
	2.5 Email Marketing	76
	2.5.1 Types of emails	79
	2.5.2 Significance of Email Marketing	80

	2.5.3 Email Marketing Strategy and Monitoring	81
	2.6 Mobile Marketing	86
	2.6.1 Types of Mobile Marketing	89
	2.6.2 Mobile Marketing Performance	91
	2.6.3 Advantages and Disadvantages of mobile Marketing	93
	2.7 Marketing Analytics	94
	2.8 Affiliate Marketing	97
3	**MARKETING ANALYTICS AND STRATEGY**	**103**
	3.1 Introduction	103
	3.2 Identify the best analytical approaches	106
	3.2.1 Application of Business Analysis in Retail Analytics	108
	3.3 Integrate Capabilities to Generate Insights	111
	3.3.1 Customer Relationship Management	114
	3.4 Importance of Marketing Analytics	121
	3.5 Marketing Analytics Process	127
	3.6 The Challenges of Data Analysis	135
	3.6.1 Overview of Data Analysis	135
	3.6.2 Statistical Techniques of Data Analysis	139
	3.6.3 Data Analysis: Editing, Coding, Tabular Representation of Data	141
	3.6.4 Challenges of Data Analysis	144
4	**DIGITAL BRANDING & COMMUNICATIONS**	**149**
	4.1 Introduction	149
	4.2 Advertising	151
	4.2.1 Role of Integrated Marketing Communication (IMC) in Branding	154
	4.3 Branding and communications	156
	4.3.1 Concept of Brand	156
	4.3.2 Communication	159
	4.3.3 Branding Meaning and Importance in Advertising	163
	4.3.4 Brand Communication	165
	4.3.5 Online Branding	169
	4.4 Strategic Brand Communication	171
	4.4.1 Brand Communications Plan	174
	4.4.2 Brand Communication Elements	178
	4.5 Customer Relations	179
	4.6 Building Positive Customer Relationships	182
	4.7 Sustaining Customer Relationships	187
	4.8 Negotiating the Contract	191
	4.9 Integrated Reward Philosophy	195

4.10 Benefits of Digital Branding and Online Marketing Branding 197
4.11 Digital Branding Examples 199

5 **SOCIAL MEDIA MARKETING** **203**
5.1 Introduction 203
5.2 Goals and Strategies 206
5.3 Social Media Analytics and its Needs 216
5.4 Social Media Analytics in Small and Large Organizations 219
5.5 Designing Content for Social Media Marketing 223
5.6 Creation of Paid Advertising on Social media 227
5.7 Introduction to Blogging 229
5.8 Handling posts and managing conversations on Facebook, Instagram, Twitter, LinkedIn 233
5.8.1 Facebook 233
5.8.2 Instagram 245
5.8.3 Twitter 252
5.8.4 LinkedIn 260

Author's Profile



Dr. Chandra has 10 years of teaching Experience and handled papers in Cost Accounting , Principles of Management ,Financial Management ,Management Information System , Business Communication ,Managerial Economics and various management papers. Dr. Chandra received her Master of Commerce in Periyar University Salem , Master Of Business Administration from Shrimati Indira Gandhi college .Dr. Chandra received her Master Of Philosophy and Doctoral Of Philosophy in Management Studies from Jamal Mohamed College ,Tiruchirappalli . Professor Chandra Award as Best Faculty by Indian Academic Researchers Association and Best Teacher by ESN Publication Chennai. Dr. Chandra has two Patent right in IPR of India, Published 13 Papers in National and International journals and Participated in 25 webinars and 8 Faculty Development Programs. Dr. Chandra update her knowledge and Complete Swayam online Cource in Financial Market & Emerging Business Models ,Cost Accounting , Introduction to research , Research Ethics ,E-Commerce , Principles of Marketing .Dr.Chandra act as a resource person and delivered lectures in Annai Women 's College Karur , Jamal Mohamed College (Autonomous) Tiruchirappalli, Theivanai Ammal College for Women Villupuram , V.H.N.S.N College (Autonomous), Virudhunagar, Sri Saradha College for Women (Autonomous), Perambalur. Dr.Chandra Organised webinars and International Conferances.



Dr. L. KALAI BHARATHI is currently serving as Principal at Swami Vivekananda Arts & Science College, Vallam, Thanjavur. She did her Masters in Business Administration Specialized in HR & Marketing at SASTRA, Deemed University, Thanjavur. and did her MPhil in Management at Alagappa University, Karaikudi. She did her PhD in Management at Bharathidasan University, Trichy. She has been qualified with SET in Management in the year 2018. She has around 17 years of academic teaching experience and 6 years of administrative experience. She has published several papers at International and National journals. As a Research Advisor in the Department of Management Studies, She is guiding more no of Ph.D students.

Scientific International Publishing House

ISBN
978-93-5757-570-6



INTRODUCTION TO CAPITAL MARKETS

Authors

Dr. R. THIRUGNANASOUNDARI

Dr. MONISHA DEVI PURUSHOTHAMAN

Dr. G. RAJESH

INTRODUCTION TO CAPITAL MARKETS

AUTHORS

Dr. R. THIRUGNANASOUNDARI

Dr. MONISHA DEVI PURUSHOTHAMAN

Dr. G. RAJESH

Published by

L ORDINE NUOVO PUBLICATION

academicbookpublication@gmail.com

www.nuovopublication.com

Book Title	:	**INTRODUCTION TO CAPITAL MARKETS**
Author	:	**Dr. R. THIRUGNANASOUNDARI** **Dr. MONISHA DEVI PURUSHOTHAMAN** **Dr. G. RAJESH**
Book Subject	:	Business Administration, Commerce & Economics
Book Category	:	Authored Book
Copy Right	:	Author
First Edition	:	November 2023
Book Size	:	B5
Paper	:	21 kg, Maplitho NS
Price	:	Rs.900/-
Published by	:	**L ORDINE NUOVO PUBLICATION** E-mail:academicbookpublication@gmail.com www.nuovopublication.com Mobile:99442 12131.

ISBN Supported by

Raja Ram Mohan Roy National Agency for ISBN, New Delhi – 110066 (India)

ISBN: 978-93-92995-97-2

ISBN 939299597-0

9 789392 995972

ABOUT THE AUTHORS



Dr. R. Thirugnanasoundari M. Com., MBA., M.Phil (Mgt)., Ph.D . She has been working as an Assistant Professor & Head, Department of Business Administration at National College (Autonomous), Trichy. She has 15 years teaching experience at the same institution. She was awarded Outstanding teacher for the year 2020 from National College. She has been services as Co-ordinator of Rotaract club in National College from the year 2011. She got two awards, Best Co-ordinator for the year 2021-2022 and outstanding coordinator for the year 2022-2023 from Rotary International 3000. She has published 5 research papers in national & international level. She also presents a paper in International conference At Malaysia. She has organized seminar, workshop and Training programmes (FDP) and she delivered special lectures in various institutions. She has awarded Institution Minor Research Project fund from National College, Trichy. She is lifetime member of Indian Accounting Association. Her moto is ,"life is what you make out of it"



Dr.Monisha Devi Purushothaman, MBA., M.Sc (Psy)., M.Phil., Ph.D (Mgt) Assistant Professor, Department of Business Administration, St. Joseph's College (Autonomous), Tiruchirappalli. She worked as an ED Cell Coordinator, National College (Autonomous) Trichy. And she got the Best outgoing student award in MBA. Her area of specializations are HR, Marketing and Systems. She also completed certificate courses on Counselling and Psychology. She acted as resource person, handled sessions and delivered talks under the topics Personality Development, Leadership, Communication Skills, Stress Management, Self-efficacy, Emotional Intelligence and so on. She organised a One-day state-level workshop on Entrepreneurial Development and various management events. She published various papers in International and National level conferences and presented papers under the titles International Trade Policy of India, Business Intelligence, Ethical Business, Spiritual Leadership for Management, Training and Development, etc.



Dr. G. Rajesh has completed MBA., M.A., M.Phil., and Ph.D. He is working as an Assistant Professor of Economics at the Department of Business Administration, National College (Autonomous) Trichy and Teaching Assistant from the Department of Economics and Rural Development, Alagappa University, Karaikudi and he worked as an Asst. Prof. of Economics, Dept. of Commerce, Mahendra Arts & Science College, Namakkal. During the academic year 2022 April, he received fund fromTamil Nadu State Council for Higher Education (TANSCHE) for National seminar and He was granted a Ph. D. fellowship by the Indian Council of Social Science Research (ICSSR), New Delhi, in addition to two grants for national seminars. During his Ph.D. time, he received LANTERN Award for research (2014-15). In 2015-16 he wasan Economics Department Forum President at Bharathidasan University and he received 2 Gold medals in NCC. He has Published 15 Research papers and More than eight Invited Talks delivered. He has awarded Institution Minor Research Project fund from National College, Trichy.

Published by
L ORDINE NUOVO PUBLICATION
academicbookpublication@gmail.com
www.nuovopublication.com

ISBN 939299597-0
9 789392 995972



MR. MUKUL M. BARWANT



MR. BALWANT SINGH



MS. SHIVANGI TRIPATHI



MS. SANTVANA TYAGI



MS. SNEHA DWIVEDI



DR. A. PRAMILA



DR. VINITA C. KARANDA



DR. AISHA KAMAL



DR. VINAY KUMAR SINGH



DR. ALOK KUMAR SINGH

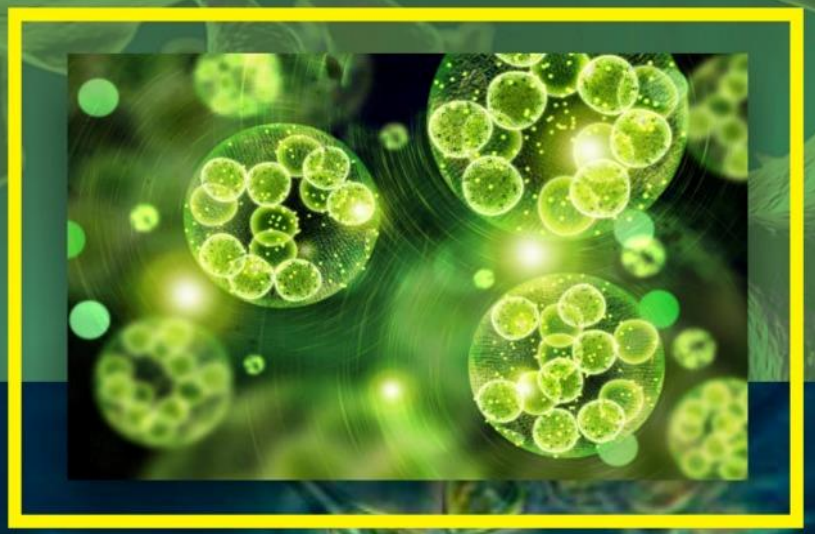
GENIC BOOKS
Genic Books Publishers Pvt. Ltd.
22 Maruti City Extension, Shamshabad Road,
Agra 282001 Uttar Pradesh
Contact : 9058586680, 9557613322
Email : genicpublication@gmail.com
Website : www.genicpublication.com

ISBN: 978-81-966376-3-7
2023 ₹1010/-

ALGAL FUNGAL AND MICROBIAL RESEARCH

GENIC BOOKS

ALGAL FUNGAL AND MICROBIAL RESEARCH



MR. MUKUL M. BARWANT, MR. BALWANT SINGH,
MS. SHIVANGI TRIPATHI,MS. SANTVANA TYAGI,
MS. SNEHA DWIVEDI, DR. A. PRAMILA,
DR. VANITA C. KARANDE, DR. AISHA KAMAL,
DR. VINAY KUMAR SINGH, DR. ALOK KUMAR SINGH

Algal, Fungal and Microbial Research

Editors:

Mr. Mukul M. Barwant, Mr. Balwant Singh,
Ms. Shivangi Tripathi, Ms. Santvana Tyagi,
Ms. Sneha Dwivedi, Dr. A. Pramila,
Dr. Vanita C. Karande, Dr. Aisha Kamal,
Dr. Vinay Kumar Singh, Dr. Alok Kumar Singh

GENiC BOOKS

Genic Books Publishers Pvt. Ltd.

GENIC BOOKS Published By

GENIC BOOKS PUBLISHERS PVT.LTD.

22 Maruti City Extension, Shamshabad Road, Agra – 282001 (Uttar Pradesh)
9058586680, 9557613322
Email : genicpublication@gmail.com
Website: www.genicpublication.com

Algal, Fungal and Microbial Research

Editors: **Mr. Mukul M. Barwant, Mr. Balwant Singh, Ms. Shivangi Tripathi, Ms. Santvana Tyagi, Ms. Sneha Dwivedi, Dr. A. Pramila, Dr. Vanita C. Karande, Dr. Aisha Kamal, Dr. Vinay Kumar Singh, Dr. Alok Kumar Singh**

© Publisher

Ist Edition 2023
ISBN: 978-81-966376-3-7
PRICE: 1010.00

All rights including copyrights and rights are reserved. No part of this publication may be reproduced, stored in a retrivel system, transmitted or utilized in forms or by any means including electronic, mechanical, photocopying, recording or otherwise or stored, without the prior permission of the copyright owner Editors. Publishers and the editors shall not be responsible for any liability arising on account of any civil or criminal proceeding (s) in any court/ Judicial body under any law for the time being in force. Please do not participate in or do not encorage piracy of copyrighted materials in violation of the editors rights. All disputes are subject to Agra jurisdiction only.

The responsibility for facts stated, opinion expressed or conclusions reached and plagiarism, if any in this book is entirely that of the author. Neither the publisher nor the editors will be responsible for them whatsoever.

Printed in India
Published by Divyansh Kumar for Genic Books Publishers Pvt. Ltd., Agra.
Laser Typesetting at Singh Computer Classes, Meerut.
Printed by D.K. Fine Art Press Pvt. Ltd. New Delhi-110052.

Content

Chapter Number	*Chapter Title*	*Page Number*
	Section-I	**01-117**
1.	AN OVERVIEW OF PRODUCTION OF BIOFUELS FROM ALGAE: POTENTIAL AND CHALLENGES	01-10
2.	A REVIEW ON ANTIOXIDANT, ANTICOAGULANT AND ANTIANGIOGENESIS POTENTIAL OF FUCOIDAN FROM BROWN SEAWEEDS	11-17
3.	SECONDARY METABOLITES IN ALGAE	18-28
4.	EUGLENOIDS IN FRESH WATER KHELNA RESERVOIR OF MAHARASHTRA	29-33
5.	IMPACT OF AIRBORNE ALGAE ON HUMAN HEALTH	34-38
6.	MARINE ALGAE AN OVERVIEW: UNLOCKING THE DEVELOPMENTAL PROSPECTIVE	39-47
7.	ALGAL POLYSACCHARIDES: THE POTENTIAL MEDICINES	48-58
8.	EXPLORING ALGAE AS A NOVEL SOURCE FOR SUSTAINABLE TEXTILES	59-65
9.	A REVIEW OF THE FABRICATION OF METAL NANOPARTICLES USING ALGAE	66-75
10.	AGRICULTURAL IMPORTANCE OF ALGAE	76-86
11.	ROLE OF ALGAE IN HUMAN WELFARE	87-94
12.	THE TYPICAL SUSPECT: HOW TO COLLABORATE ON THE DEVELOPMENT OF HEALTHIER MEAT PRODUCTS	95-104
13.	A QUALITATIVE AND QUANTITATIVE EVALUATION OF THE MICROALGAE AND SEAWEED AS FEEDSTUFF FOR RUMINANTS	105-117
	Section-II	**118-254**
14.	CHECKLIST OF FUNGI FROM KALSUBAI AREA, MAHARASHTRA STATE– PART 1	118-122
15.	BOTANICAL FUNGICIDES: AN UPDATED REVIEW	123-130
16.	NEW ANTIFUNGAL AGENTS AND THERAPEUTIC APPROACHES TO OVERCOME THE CRISIS IN ANTIFUNGAL THERAPY	131-158
17.	FUNGI AND FUNGICIDES	159-167
18.	ENDOPHYTES A BOON FOR SUSTAINABLE CROP PRODUCTION: AN INCLUSIVE REVIEW	168-177

19.	STUDY OF IMPACT OF SEED BORNE MYCOFLORA OF *C. arietinum* ISOLATED FROM JABALPUR DISTRICT (M.P.) ON POST HARVEST LOSSES	178-181
20.	DISTRIBUTION OF AQUATIC FUNGI IN FRESH WATER HABITAT	182-195
21.	DISTRIBUTIONAL RECORDS OF SOME NOTEWORTHY MEMBERS BELONGING TO ORDER *BOLETALES* OF CORTICIOID FUNGI FROM DISTRICT CHAMBA OF HIMACHAL PRADESH	196-206
22.	EXPLORING ENDOPHYTIC FUNGI ASSOCIATED WITH *PRUNUS* SPECIES: AN OVERVIEW	207-213
23.	A COMPREHENSIVE REVIEW ON AMAZING AND BENEFICIAL APPLICATIONS OF LICHEN	214-220
24.	ROLE OF ARBUSCULAR MYCORRHIZAL FUNGI IN ALLEVIATING HEAVY METAL STRESS FROM AGRICULTURAL SOIL	221-233
25.	A COMPREHENSIVE STUDY OF BIOLOGICAL PROPERTIES OF FUNGAL ENDOPHYTES: A REVIEW	234-244
26.	IMPACT OF AIR-BORNE FUNGI ON HUMAN HEALTH	245-254
	Section-III	**255-336**
27.	ECOLOGY AND BIOTECHNOLOGICAL APPLICATIONS OF MARINE CYANOBACTERIA: A REVIEW	255-265
28.	A STUDY ON CELLULOSE AND ITS DEGRADATION: A PROMISING BIOMATERIAL	266-282
29.	TOP FIVE PATHOGENIC BACTERIA IN PLANT PATHOLOGY	283-292
30.	THE ROLE OF *Aspergillus tubingensis* IN MYCOREMEDIATION OF POLYURETHANE	293-299
31.	CYANOBACTERIA'S RISING INTERESTS IN NANOTECHNOLOGY AND GENETIC ENGINEERING TO BOOST PRODUCTION FOR FUTURE APPLICATIONS	300-314
32.	THE MAIN CULPRITS FOR BIOFOULING, DISCOLORATION, STAINING, AND BIODETERIORATION OF CULTURAL HERITAGE	315-329
33.	ROLE OF MICROORGANISMS IN ECOSYSTEM RESTORATION	330-336
	Appendix	337-338
	About the Authors	339-348

CHAPTER

27

ECOLOGY AND BIOTECHNOLOGICAL APPLICATIONS OF MARINE CYANOBACTERIA: A REVIEW

R. Anburaj[1,3]*, G. Rosline Jebapriya[2], MA. Nabeel[3], K. Kathiresan[3] and K. Arun[1]

Abstract

Cyanobacteria have played a substantial role in the evolution of life by creating an oxygenic atmosphere through the process of photosynthesis. They have specific adaptive strategies to survive in extreme environments. They are ubiquitous in nature and can be spotted in both marine and freshwater ecosystems and are especially rich in oligotrophic waters of the tropical and subtropical marine environment. Cyanobacteria in the mangrove ecosystem provide fixed nitrogen, carbon, bioremediation and secreting plant growth-promoting substances etc, to the vegetation. Diversity of cyanobacteria in this biome has been traditionally underestimated. Cyanobacteria still play a significant role in modern coral reef ecosystems by forming a major portion of epiphytic, epilithic, and endolithic communities as well as of microbial mats. Cyanobacteria have gained a lot of attention in recent years because of their potential applications in the field of biotechnology. A wide range of secondary metabolites exhibiting pharmacodynamic properties such as antibacterial, antiviral, antifungal, anti-inflammatory and anticancer have been exhibited. In addition to these applications, cyanobacteria are also used in aquaculture, treatment of wastewater, food, fertilizers, vitamins, toxins, enzymes and pharmaceuticals. We present an overview of the literature describing the presence of cyanobacteria in marine and mangrove ecosystem and uses of these in various industries which provide an outlook on the challenges and future prospects of the field of cyanobacterial biotechnology. Future research should focus on isolating new cyanobacterial strains from

mangrove vegetation producing high value products and genetically modifying existing strains to ensure maximum production of the desired products.

Keywords: *Biotechnology, Cyanobacteria; Mangroves; Pharmacodynamic.*

[1]PG and Research Department of Biotechnology and Microbiology, National College (Autonomous), Tiruchirapalli, Tamil Nadu, India.
[2]Department of Marine Science, Bharathidasan University, Tiruchirappalli, Tamil Nadu, India.
[3]Centre of Advanced Study in Marine Biology, Faculty of Marine Sciences, Annamalai University, Parangipettai, Tamil Nadu, India.
*anbu_nanthu@rediffmail.com

Introduction

Cyanobacteria are the largest group of photosynthetic prokaryotes, capable of fixing atmospheric carbon and nitrogen (Stal, 2000). Cyanobacteria exits in a variety of habitats. The cyanobacteria comprise a large component of marine plankton with global distribution. Cyanobacteria are abundant in most marine habitats due to their preference for alkaline conditions and an ability to tolerate high salt concentrations. Cyanobacterial species show resistance towards osmotic shock, extremes of temperature and reducing conditions. The most important discovery of the last two decades has been the great contribution of the cyanobacteria in the oceans (Waterbury and Rippka, 1989; Waterbury, 2006; Anburaj, 2011) and to the pelagic food web of the ocean. According to Desikachary (1959) about 20% of all known cyanobacteria occur in saline conditions and a majority of them are truly Marine. Most marine forms grow along the shore as benthic vegetation in the zone between the high and low tide marks. They have also been reported to occur in mangrove biotopes (Kathiresan and Bingham, 2001; Kathiresan and Qasim, 2005; Anburaj *et al.*, 2011). The unicellular cyanobacteria belonging the genus *Synechococcus* (Anburaj 2011) are an important component of phytoplankton in many marine and freshwater planktonic ecosystems. But the unicellular cyanobacteria especially in mangrove biotope are little focused (Sakthivel, 2004; Anburaj 2011; Anburaj et al., 2011).

Cyanobacteria in marine biotope

Marine cyanobacteria are found in all the world's oceans but are most abundant in warmer temperate and tropical regions. The taxonomic diversity of marine cyanobacteria does not differ markedly from that of cyanobacteria found in terrestrial and freshwater habitats. The cyanobacteria are currently placed under five groups: Chroococcales, Pleurocapsales,

Oscillatoriales, Nostocales and Stigonematales (Anburaj 2011). Representatives from each of the five major taxonomic have been isolated from marine sources. However, particular marine habitats (intertidal and subtidal zones, coral reefs, salt marshes, and the open ocean) often harbor a restricted and characteristic diversity of forms which may differ spatially with geographical locations and temporarily with season (Anburaj, 2005; Anburaj, 2011). The intertidal and subtidal zones contain a diverse assemblage of cyanobacteria that are typically found attached to solid substrates such as rocks, mollusk shells, pieces of wood and eukaryotic macroalgae. Pleurocapsalean forms are characteristic of intertidal and subtidal habitats, where they frequently grow as epiliths or endoliths on calcareous substrates and as epiphytes on macroalgae. Compared to intertidal region, salt marshes support low diversity of cyanobacteria but in several cases, cyanobacteria are conspicuous in salt marshes as a result of the formation of dense algal mats. Oscillatorian forms usually make up the principal component of cyanobacteria in the algal mats, but a wide variety of unicellular and heterocystous forms are also usually present.

The open ocean harbors low numbers of plantonic forms of cyanobacteria, as compared to fresh water habitats (Whitton, 1973), where over 100 species of planktonic cyanobacteria have been described and 20 are capable of forming dense water blooms. The best known of water bloom is *Trichodesimium*, an Oscillatorian cyanobacterium that often forms dense blooms occupying vast areas in subtropical regions. This group of cyanobacteria is of interest to biological oceanographers because of its reputed ability to fix nitrogen. However, *Trichodesmium* has not been successfully cultured till date for experimental studies and applications.

Lyngbya majuscula (Oscillatoriacea), also known as *Microcoleus lyngbyaceus* (Burja *et al*, 2002) is a filamentous, non-heterocystous marine cyanobacterium inhabiting tropical and sub-tropical estuarine and coastal waters (Anburaj, 2011). It is composed of thin, unbranched filaments, often olive- grey in colour. *L. majuscula*is is often found forming benthic mats loosely attached to substrates such as seagrass, macroalgae or rock outcrops. Additionally, mats can rise to the surface through the accumulation of gas bubbles (Dennison *et al.*, 1999). This marine cyanobacterial species forms seasonal blooms in the Deception Bay Pumicestone passage areas of Moreton Bay, Queensland, for nearly a decade (Dennison & Abal, 1999) and the blooms have increased in severity and extent since early 1990. A similar seasonal change has been recorded in other cyanobacterial species in the salt marshes by Chapman (1960). Webber (1967) has identified 30 species of cyanobacteria from a salt marsh near Massachusetts, USA. Chapman (1977) has extensively studied the cyanobacterial communities in salt marshes from Europe, Iceland, America, India and New Zealand. In India, ecology of the marine cyanobacteria has been studied extensively by Iyyengar and Desikachary (1944); Devassy et al. (1978) mainly with *Trichodesmium* species.

Cyanobacteria in mangrove biotope

Cyanobacteria constitute one of the important resources of mangrove ecosystems along the tropical coasts (Kathiresan, 2000; Kathiresan and Bingham, 2001; Sakthivel, 2004; Kathiresan and Qasim, 2005; Kathiresan, 2011; Anburaj 2011; Kathiresan et al., 2011;

Kathiresan et al., 2013; Kathiresan et al., 2016; Kathiresan et al., 2018). They colonize any submerged surface of sediments, roots, aerial roots, branches and tree trunks of mangroves (Kathiresan et al., 2000; Palaniselvam and Kathiresan, 2002; Nabeel *et al*., 2009; Anburaj 2011; Kathiresan et al., 2011**;** Kathiresan et al., 2014; Kathiresan et al., 2016). The report of Millard and Broekhuysysen (1970) is the early reference that has listed the cyanobacteria associated with mangrove along the southeast African coast. In India, the entire mangroves region of the Sundarbans is reported to be rich in benthic algal forms (Santra and Pal, 1988). Their populations in other mangrove areas of India have also been documented (Palaniselvam and Kathiresan, 2002; Sakthivel, 2004; Anburaj, 2011).

Cyanobacteria are reportedly present in the mangrove ecosystems of many countries (Anburaj 2011). Mangroves are occupied by diverse cyanobacterial communities, which reside on leaf, root litter, live roots, and often from extensive mats on the surrounding sediments; many of these communities are capable of fixing atmospheric nitrogen (Hoffmann, 1999). The genera *Oscillatoria*, *Lyngbya, Phormidium* and *Microcoleus* are widespread in these habitats, as heterocystous genera, like *Scytonema*, in some areas (Hoffmann, 1999). The taxonomic survey of the cyanobacteria in a red mangrove forest of the Brazil estuaries has revealed a total of 15 taxa in 8 families: *Synechococcaceae* (2 taxa), *Chroococcaceae* (1 taxa), *Hyellaceae* (1 taxa), *Xenococcaceae* (1 taxa), *Oscillatoriaceae* (2 taxa), *Scytonemataceae* (2 taxa), *Phormidiaceae* (5 taxa), and *Pseudannabaenaceae*(2 taxa) (Nogueira and Ferreira Correia, 2001). A total of ten genera of cyanobacteria has been recorded in mangroves; *Anabena, Rivularia, Aphanocapsa*, *Merismoppedia, Lyngbya*, *Microcoleus, Oscillatoria, Phormidium*, *Schizothrix*, and *Spirulina* (Kyaruzi *et al.*, 2003).

The cyanobacteria colonize various parts of the tree mostly the aerial roots. The pneumatophores give microhabitat to specific cyanobacterial populations. Interestingly the cyanobacteria on the aerial roots exhibit sharp vertical zonation (Kathiresan and Bingham, 2001). Non-heterocystous, particularly filamentous cyanobactera resembling *Microcoleus* sp., colonize the central zone, and by coccoidal cyanobacteria resembling *Aphanothece*sp., mixed with unidentified filamentous cyanobacteria colonize the upper part (Venkataraman, 1981). *Lyngbya* sp., *Polysiphonia* sp., and *Oscillatoria* sp., are common epiphytic cyanobacteria of submerged root system of *Rhizophora* sp., (Krishnamurthy and Jayaseelan, 1983). The pneumatophores of mangroves are colonized by five cyanobacterial species; *Calothrix*, *Anabaena*, *Lyngbya*, *Hydrocoleum*, and *Schizothrix* as reported from Sundarbans (Santra *et al*., 1988).

Cyanobacteria are an important component of the microbial flora of mangroves. Six species dominantly occur in the root-soil of mangroves and they are *Spirulina subsalsa, Phormidium tenue, Synechocystis salina, Oscillatoria willei* and *O. cortiana*. Their counts vary between $3.1x10^3$ and $4.1x10^4$ colony forming units per gram of soil with the maximum occurrence during summer (May) and the minimum in post monsoon (December) along the east coast of India (Nabeel *et al*., 2009). The planktonic cyanobacteria are reportedly belonging to the species of *Trichodesmium, Synechococcus, Aphanothece, Gloeocapsa, Gloeothece, Merismopedia, Oscillatoria, Johannes baptistia, Microcystis* and *Stigonema* in Sundarbans (Santra*et al*., 1988; Saravanakumar et al., 2016). Three species of planktonic cyanobacteria

Anabaena sp., *Oscillatoria* sp., and *Trichodesmium* sp., have been recorded in Pichavaram mangroves (Anburaj 2011). Population densities of planktonic cyanobacterial species decrease in monsoon and increases in pre-monsoon periods (Banerjee and Santra, 2001). The change in population density of cyanobacteria is due to the variations in environmental factors such as temperature, salinity, light, *etc*. (Banerjee and Santra, 2001; Anburaj 2011).

A study on mangrove-associated cyanobacteria has recorded the presence of 17 cyanobacterial species in the Muthupet estuary (Selvakumar and Sundararaman, 2001). This study reveals the unique associates of cyanobacteria on mangrove trees. Cyanobacterial species *Aphanocapsa koordersi*, *Johannes baptistia pellucid*, *Oscillatoria vizagapatensis*, and *O. tenuis* colonize on *Avicennia marina*. Cyanobacterial species, *Porphyosiphon natarsii*, *Phormidium* sp., *Oscillatoria calcuttensis*, and *Schizothrix telephorides* are found only on *Aegiceras corniculatum*. Cyanobacterial species *Aphanocapsa bullosa* and *A. littoralis* are specific to *Excoecaria agallocha* and the cyanobacterial species *Oscillatoria claricentrosa* occurs only on *Suaeda maritima* (Selvakumar and Sundararaman, 2001). The species specificity may be attributed to the root exudates and also to the environmental conditions. The root exudates may play a key role in forming a community structure by selectively stimulating and enriching certain groups of bacteria (Burgmann*et al*., 2005).

Ecological role of cyanobacteria in mangroves

Mangroves are among the most productive ecosystems in the world (Kathiresan and Bingham, 2001). They support rich macro and microbial floral components. The interactions of mangrove trees with soil and associated microbes are complex, as the trees and other biota must cope with a harsh intertidal environment (Anburaj 2009; Anburaj et al., 2012). The sedimentary bacteria play a significant role in energy flows and cycles of tropical mangrove forests. The bacteria are very high in densities and productivity in mangrove sediments of tropical Australia (Alongi et al., 2001; Anburaj et al., 2020), which is 2 to 10 times higher than that has been reported for other marine sediments. Mangrove soils are a source of microbially mediated gases, such as CO_2, CH_4, N_2, and N_2O (Anburaj 2011; Anburaj et al., 2017; Anburaj et al., 2020b). It is therefore, important to have better knowledge of rates and pathways of microbial processes in these tropical habitats to better estimate the role of mangroves in global carbon and nitrogen cycling.

Nitrogen is an essential biogenic component, responsible for productivity of any ecosystem. The nitrogen gas enters into the biosphere by the process (Tyagi, 1973), in which only a few species of microorganisms such as cyanobacetria, azotobacters, azosprillum, rhizobium is involved. Many of the cyanobacterial species have the power of nitrogen fixation by the presence of very special enlarged cells called heterocysts. According to Tyagi (1973), Apart from microbial nitrogen fixation, which is its prime function, the heterocyst is also credited with many other biological functions such as reproduction (Tyagi, 1973).

Biotechnological potentials of cyanobacteria

Cyanobacteria constitute a potential resource in varied applications such as mariculture, food, feed, fuel, fertilizer, medicine, industry and in combating pollution. They are important for

the production of glycerol, polysaccharides, lipids and fatty acids, which are needed for chemical industries. An exciting area of cyanobacterial research is biosynthesis of nanoparticles. Many microorganisms produce inorganic materials either intra- or extracellularly. For example, photoautotrophic cyanobacterium *Plectonema boryanum* forms extracellular silver nanoparticles (Langke*et al*., 2007) and *Shewanella* sp., produces intracellular gold nanoparticles by microbial reduction of aurium chloride ions (Konishi *et al*., 2006; Anburaj et al., 2020a; Anburaj et al., 2022). Similarly, unicellular cyanobacteria, *Synechococcus elongatus* and *Gloeocapsa* sp., are known to synthesize silver nanoparticles (Asmathunisha et al., 2012; Anburaj, 2011; Asmathunisha et al., 2018; Anburaj et al., 2021).

Food and feed

A variety of fine chemicals such as pigments, vitamins and enzymes with varied applications can be obtained on a commercially viable scale from cyanobacteria. A number of cyanobacteria are rich in vitamins and many can excrete them into the surrounding environment (Borowitzka, 1988). The carotenoids and phycobiliproteins, characteristic of cyanobacteria have high commercial value. They are used as natural food colourants, as food additives to enhance the colour of the flesh of Salmonid fish and to improve the health and fertility of cattle (Thajuddin and Subramanian, 2005). *Phormidium valderianum* is an excellent source of phycocyanin, a blue natural colorant useful as a phycofluor in diagnostics (Anburaj, 2011).

Cyanobacteria secrete enzymes that can be exploited commercially in large-scale production of enzymes such as beta lactamase, protease and lipase (Prabhakaran, et al., 1994). Several common and unique sequence-specific endonucleases are known from *Anabaena cylindrical* (Acy I), *Anabaena flos-aquae* (Afl I &Afl III), *Anabaena variabilis* (AvaI&AvaII), *Anabaena* 54 *variabilis UW* (AvrII), *Microcoleus*sp. *UFEX* 2220 (MstII), *Nostoc*sp. *PCC* 7524 (Nsp C I), which can be marketed at low cost since relative biomass production of cyanobacteria is much less expensive than bacteria (Elhai and Wolk,1988). Cyanobacterial isolates with capacity to mineralize organic phosphorus have been reported with alkaline phosphatase activity. Enzymes such as chitinase, L-asparaginase, L-glutaminase, amylase, protease, lipase, cellulase, urease and superoxide dismutase have been reported from cyanobacteria (Elhai and Wolk,1988).

Pharmaceuticals

Cyanobacteria in general and marine forms in particular are one of the richest sources of known and novel bioactive compounds including toxins with wide pharmaceutical applications (Raghavan et al, 2002; Annamalai et al., 2007). Gustafson *et al*. (1989) have reported anti-HIV activity of marine cyanobacterial compounds from *Lyngbya lagerheimii* and *Phormidium tenue.* A massive programme of screening of extracts from the large culture collection of marine cyanobacteria in our research facility for antiviral, anti-bacterial, anti-fungal and immuno-modulatory activities has resulted in recovery of a compound from marine *Oscillatoria laete-virians BDU* 20801 that shows anti-candida activity (Deth, 1999).

Biofertilizer

The role of N_2-fixing cyanobacteria in maintenance of the fertility of rice fields has been well substantiated and documented all over the world. In India alone, the beneficial effects of cyanobacteria on yield of many rice varieties have been demonstrated in a number of field locations (Kathiresan and Bingham, 2001). A variety of cyanobacterial strains colonize rice fields wherein heterocystous species are capable of fixing atmospheric nitrogen. However, several non-heterocystous cyanobacteria are also able to fix atmospheric nitrogen under microaerophilic conditions. *In situ* estimations using acetylene reduction technique have shown an addition of 18–15 kg N ha^{-1} yr^{-1} due to the activity of diazotrophic cyanobacteria (Waterbury *et al.,* 1979). Beneficial effects of cyanobacterial inoculation have also been reported on a number of other crops such as barley, oats, tomato, radish, cotton, sugarcane, maize, chilli and lettuce (Kaushik and Venkataraman, 1979).

Cyanobacterial toxins

Fresh water cyanobacteria blooms that have been implication on human livestock intoxications have been extensively studied (Carmichael, 1997). Bloom of marine cyanobacteria is also becoming an increasingly familiar occurrence within the tropical and sub- tropical regions of the world. Bloom forming taxa belonging to the order Chroococcales and Oscillatoriales produce marine toxic compounds. For example, *Synechococcus* species produce linonelenic acid and phycocyanin compounds with antibiotic property, while *Synechocystis* species produce cytotoxic compounds such as nakitriol (Nagle et al., 1995).

Cyanobacteria are rich source of toxic compounds as well antimicrobial and antiviral compounds (Nagle et al., 1995). Jaspers et al, (1996) have alone reported a total of 208 compounds while Marinlit (2001) recorded 424 compounds, of which active compounds are mainly used for the enzyme's inhibition, herbicides, antimycotics, anti-malarial and immunosuppressive actions. Following the current decline in many natural product discovery programmes globally, a special focus is given on marine cyanobacteria-derived compounds for screening in new pharmaceutical property.

Concluding remark

Although cyanobacteria are known for their biological potential with anti tumor, anti-cancer, anti-HIV, anti-fungal, anti-bacterial, anti-oxidant, food additives, bio fertilizer, dye degradation, nanoparticle synthesis, a very few such compounds have been so far available. Marine cyanobacteria especially from mangrove biotope are one of the richest sources of known and novel bioactive compounds with wide range of applications. Hence, isolation and identification of new marine cyanobacterial species from marine environments such as mangrove environment will pave the possible way to identify novel compounds for their utilization in pharmaceutical, agricultural and food industries.

References

1. Alongi DM, Wattayakorn G, Pfitzner J, Tirendi F, Zagorskis I, Brunskill GJ. 2001. Organic carbon accumulation and metabolic pathways in sediments of mangrove forests in southern Thailand. *Marine Geology.* 179: 85-103.

2. Anburaj R. 2009. Effect of rhizobacteria on salinity induced changes in Sesuvium portulacastrum L. M.Phil., Thesis. Annamalai Univarsity,Tamil Nadu, India. Pp.98.
3. Anburaj R. 2011. Studies on marine cyanobacteria (chroococcales) isolated from mangrove biotope for their possible utility. Ph.D., Thesis. Annamalai Univarsity,Tamil Nadu, India. Pp.218.
4. Anburaj R, Saravanakumar K, Gomathi V, Yuvaraj J, Kathiresan K. 2011. Calcium removal from aqueous solution by marine cyanobacterium, gloeocapsa species: adsorption kinetics and equilibrium studies. Int. J. Pharma. Appl. 23: 195-201.
5. Anburaj R, Nabeel M.A, Sivakumar T, Kathiresan K. 2012. The role of Rhizobacteria in salinity effects on biochemical constituents of the halophyte *Sesuvium portulacastrum* L. Russ J Plant Physiol. 59: 115-119.
6. Anburaj R, Roseline Jebapriya G, Kathiresan K. 2017. Biosorption of Cadmium by Mangrove - Derived Cyanobacteria (*Gloeocapsa* sp ARKK3). Statistical Approaches on Multidisciplinary Research 1:82-94.
7. Anburaj R, Kathiresan K, Roseline JebaPriya G. 2020a. Molecular Identification of Marine Cyanobacterium- Phormidium ARKK2 from Mangrove Environment. Int. J Creative Resea Thoughts 8 (10):902-910.
8. Anburaj R, Kathiresan K, Roseline Jebapriya G. 2022. Molecular Characterization Of Unicellular Cyanobacteria Isolated From Mangrove Biotope. Recent Trends in Life Sciences 1, Pp.43-52.
9. Anburaj R, Roseline Jebapriya G, Asmathunisha N, Kathiresan K. 2020. Antibacterial Activity of Mangrove-Derived Marine Cyanobacteria. International Journal of Scientific Research and Engineering Development 3 (2):542-550.
10. Anburaj R, Roseline Jebapriya G, Kathiresan K. 2021. Enhancement of Textile Dye Degradation by Mangrove-Derived Cyanobacteria (*Phormidium* ARKK2). Health, hygiene, sanitation and Environment at pandemic times 1: Pp.63-69.
11. Anburaj R, Roseline Jebapriya G, Saravanakumar K, Kathiresan K. 2020b. Bioremoval of Lead by Mangrove-Derived Cyanobacteria (*Synechococcus elangatus* ARKK1 Global Environmental Governance, Policies and Ethics 2, 13-31.
12. Anburaj R. 2005. Studies on antimicrobial properties of bivalves. M.Sc., Thesis. Annamalai Univarsity,Tamil Nadu, India. Pp.85.
13. Annamalai N, Anburaj R, Jayalaksmi S, Thavasi R. 2007. Antibacterial activities of green mussel (*Perna vridis*) and edible oyster (*Crassostrea madrasensis*) Resarch Journal of Microbiology, 2 (12): 978-982.
14. Asmathunisha N, Kathiresan K, Anburaj R, Nabeel MA (2010) Synthesis of antimicrobial silver nanoparticles by callus and leaf extracts from saltmarsh plant, *Sesuvium portulacastrum* L. Colloids and surf B: Biointerfaces 79 (2):488-493.
15. Asmathunisha N, Anburaj R, Kathiresan K (2018) Silver and Gold Nanoparticles by Mangrove-Derived Cyanobacteria. *J Advances Nanomaterials* 3 (3) 37-43.
16. Banerjeee A, Santra CS. 2001. Phytoplankton of the reviers of Indian Sunderban mangrove estury. *Indian Biologist* 33: 67-71.
17. Borowitzka MA. 1994. Products from algae. In: S. M. Phang, K. Lee M. A. Borowitzka and B. Whitton (eds.). Algal biotechnology in the Asia-Pacific Region. Institute of Advanced Studies, University of Malaya: Kuala Lumpur.

18. Burgmann R, Kogan M, Steblov G, Hilley G, Levin V, Apel E.2005. Interseismic coupling and asperity distribution along the Kamchatkasubduction zone, *J*. Geophys. Res 110; 17.
19. Burja MA, Banaigs E, Abou M, Burgers JG, Wright PC. *Tetrahedran*, 2001;57: 9347-9377.
20. Carmichael WW. Cyanobacteria secondary metabolites--the cyanotoxins. *J. Appl. Bacteriol* 1992;72(6): 445-459.
21. Chapman VJ. Salt marshes and salt deserts of the world. New York: Interscience. 1960.
22. Chapman VJ. Wet coastal ecosystems. Elsevier Scientific Publ. Company, D.W. Goodall, Elsevier, Amsterdam, Oxford, New York, 1977;29: 428.
23. Dennison WC, O'Neil JM, Duffy E, Oliver P, Shaw G. 1999. Blooms of the cyanobacterium Lyngbya majuscula in coastal waters of Queensland. In Proceedings of the International Symposium on Marine Cyanobacteria, Nov. 97 (Charpy, L. & Larkum, A.W.D., eds). Bulletin de l'Institut Oceanographique, Monaco. 632.
24. Desikachary TV. Cyanophyta. Indian Council of Agricultural Research, New Delhi, 1959. 686.
25. Devassy VP, Bhattathiri PMA, Qasim SJ. *Trichodesmium phenomenon*. *Indian J. Mar. Sci* 1978;7: 168-186.
26. Elhai J, Wolk CP. Conju-gal transfer of DNA to cyanobacteria. Methods Enzymol 1988;167, 747–754.
27. Gustafson, K. R., J. H. Gadellina, R. W. Fuller, O. S. Weislow, R. F. Kiser, K. M. Snader, G. M. L. Patterson and M. R. Boyd, 1989. AIDS-antiviral sulfolipids from cyanobacteria (blue green algae). *J. Natl. Canc. Inst.*, 81: 1254-1258.
28. Hoffmann, L., 1999. Marine cyanobacteria in trophical regions: diversity and ecology. Eur. J. Physiol., 34: 371-379.
29. Iyengar, M. O. P. and T. V. Desikachary, 1944. A systematic account of some marine myxophyceae of the South Indian coast. *J. Madras Univ.*, 16: 37- 68.
30. Jasper, J.P., J.M. Hayes, A.C. Mix, and F.G. Prahl, Photosynthetic fractionation of 13 C and concentrations of CO 2 in the central equatorial Pacific during the last 225,000 years, Paleoceanography, 9, 781-898, 1994.
31. Kathiresan K, Anburaj R, Gomathi V, Saravanakumar K (2013) Carbon sequestration potential of *Rhizophora mucronata* and *Avicennia marina* as influenced by age, season, growth and sediment characteristics in southeast coast of India. J coastal conserve 17 (3):397-408.
32. Kathiresan K, SaravanaKumar K, Anburaj R, Gomathi V (2016) A simple method for assessing mangrove forest based on young plants and sesarmid crab holes. Reg. Stud. Mar Sci 7:204-210.
33. Kathiresan K, Saravanakumar K, Anburaj R, Gomathi V, Abirami G, Sunil Kumar Sahu, Anandhan S (2011) Microbial enzyme activity in decomposing leaves of mangroves. Int J Adv Biotech Res 2 (3): 382-389.
34. Kathiresan K, SaravanaKumar K, Asmathunisha N, Anburaj R, Gomathi V (2018) Biochemical markers for carbon sequestration in two mangrove species *Avicennia marina* and *Rhizophora mucornata*. Beni-Suef University J Basic and App Sci 7: 773-779.

35. Kathiresan K and S.Z. Qasim. 2005. *Biodiversity of Mangrove Ecosystems.* Hindustan Publishing Corporation, New Delhi, pp.251.
36. Kathiresan K, K Saravanakumar, R Anburaj, V Gomathi. 2016. A simple method for assessing mangrove forest based on young plants and sesarmid crab holes. Regional Studies in Marine Science, 7, 204-210.
37. Kathiresan K, V. Gomathi, R. Anburaj, K. Saravanakumar. 2014. Impact of mangrove vegetation on seasonal carbon burial and other sediment characteristics in the Vellar-Coleroon estuary, India. Journal of Forestry Research. 25, 4, 787-794.
38. Kathiresan, K. and B. L. Bingham, 2001. Biology of mangroves and mangrove ecosystems. *Adv. Mar. Biol.,* 40: 81- 251.
39. Kathiresan, K., 2000. A review of studies on Pichavaram mangrove, Southeast India. *Hydrobiologia,* 430: 185- 205.
40. Kaushik BD, and G. S. Venkataraman. 1979. Effect of algal inoculants of the yield and vitamin C content of two varieties of tomato. Plant and Soil 52, 135-137.
41. Konishi, Y., T. Tsukiyama, K. Ohno, N. Saitoh, T. Nomura and S. Nagamine, 2006. Intracellular recovery of gold by microbial reduction of AuCl4- ions using the anaerobic bacterium *Shewanella algae*. *Hydrometallurgy,* 81: 24-29.
42. Krishnamurthy, K. and P. Jayaseelan, 1983. The Pichavaram (India) mangrove ecosystem. *Int. J. Ecol. Environ. Sci.,* 9: 79- 85.
43. Langke, F. M., E. M. Fleet and G. Southam, 2007. Biosynthesis of silver nanoparticles by filamentous cyanobacteria a from a silver (I) nitrate complex. *Langmuir,* 23: 2694-2699.
44. Millard, N. and Broekhuysen, B. 1970. The Ecology of South African Estuaries: X. St. Lucia: a second report. *African Zoology* 5(2): 277-307.
45. Nabeel, M. A., S. Manivannan and K. Kathiresan, 2009. Marine cyanobacteria from Rhizosphere soil of mangroves along the east coast of India. Conservation *and management of mangroves in India,* (Zoological survey of India). 253-260pp.
46. Palaniselvam, V. and K. Kathiresan, 2002. Epiphytic cyanobacterium from mangroves. In: N. Anand, (ed.). *Algological Research in India,* 45-54pp.
47. Prabhakaran, D., G. Subramanian and L. Uma, 1994. Hydrogen photoproduction by marine cyanobacteria *Dicothrix bauriana* BDU 40481. *Physiol. Mol. Biol. Plants.,* 1: 45-57.
48. Sakthivel, K., 2004. Studies on marine cyanobacterium from mangrove Environment. Ph.D. Thesis. Annamalai University, India, 144 pp.
49. Santra, S. C. and U. C. Pal, 1988, Marine algae of Mangrove delta region of West Bengal, India: Benthic forms Indian Biologists. 20 (2): 31-41.
50. Santra, S. C., U. C. Pal, H. Maity and G. bandyopadhaya, 1988. Bluegreen algae in saline habitats of West Bengal: a systematic account. *Biol. Mem.,* 14: 81-108.
51. Saravanakumar, K, R Anburaj, V Gomathi, K Kathiresan. 2016. Ecology of soil microbes in a tropical mangrove forest of south east coast of India. Biocatalysis and Agricultural Biotechnology 8, 73-85.
52. Selvakumar, G. and M. Sundararaman, 2001.Mangrove associated cyanobacterial species in Muthupet Estuary. *Seaweed Res.Utilin.,* 23(1&2): 19-22.
53. Stal, L. J., 2000. Cyanobacteriamatand stromatolites. In: B.A. Whitton and M. Potts (eds.), The ecology of cyanobacteria. *Kluwer Academic Publ. Netherlands,* 61-120 pp.

54. Thajuddin N, and G. Subramanian. 2005. Cyanobacterial BNiodiversity and potential application in Biotechnology. Current Science 89(1): 47-57.
55. Tyagi, V.V.S. (1973) Effect of some metabolic inhibitors on Heterocyst formation in blue-green algae Anabaena doliolum. Annals of Botany. 37:361-368.
56. Venkataraman, G.S. -1981- Blue-green algae for rice production. FAO Soil Bulletins 16: 33 - 42.
57. Waterbury, J. B. and R. Rippka. 1989. The order Chroococcales. In: N. R. Krieg and J. B. Holt (eds.), Bergey's Manual of Systematic Bacteriology, 3: 1728-1746.
58. Waterbury, J., 2006. The Cyanobacteria-isolation, purification and identification. *Prokaryotes,* 4: 1053-1073.

***



IntechOpen

Infections and Sepsis Development

Edited by Vincenzo Neri, Lixing Huang and Jie Li



Chapter

Challenges in Controlling Vibriosis in Shrimp Farms

Hethesh Chellapandian, Jeyachandran Sivakamavalli, A. Vijay Anand and Balamuralikrishnan Balasubramanian

Abstract

Recently the shrimp farming has blooming as a crucial counterpart in the aquaculture industry which contribute the remarkable role in sea food production as well economy of the country. However, this could be fluctuated every year through several circumstances such as unfavorable (Poor water and soil quality) environmental factors. The environmental factors includes disease causing bacterial pathogens in the soil and water which causes the bacterial diseases in the aquatic animals, like this hectic problems are prevented through bioaugmentation strategies. The pond environment plays a vital role in determining the healthy culture system, but there is high risk for manipulation by bacterial community which takes care of waste generated in the system through *in situ* bioremediation. Due to the impact of rapidly growing bacterial diseases of shrimps throughout the world, numerous studies have been carried out to find immunostimulants, immunomodulators and biotic component that can be used against vibrio causing pathogens, and can also be used as an alternative for antibiotics. Recent research focus towards the marine resources such as microalgae, seaweed, live feeds (like artemia, copepods, rotifers), bacteriophage, and probiotics have been found to have higher potential in reducing vibriosis. Eco-based shrimp farming includes green water technology, phage therapy bio-floc technology (BFT) and integrated multi-trophic aquaculture (IMTA), these methods hold a promising alternative to antibiotics in the near future. Bacterial diseases caused by vibrios have been reported in penaeid shrimp culture systems implicating at least 14 species and they are *Vibrio harveyi, V. splendidus, V. parahaemolyticus, V. alginolyticus, V. anguillarum, V. vulnificuslogei* etc.

Keywords: Immunity, Hypoxia, Salinity, pH, Vibriosis, Probiotics

1. Introduction

Vibriosis is a bacterial disease caused by *Vibrio* which is Gram-negative, motile, facultative anaerobe bacteria of the family Vibrionaceae. It is ubiquitous throughout the world and in all marine crustaceans, including shrimp. Vibriosis is one of the major disease problems in shellfish and finfish aquaculture, especially in shrimp farming. Vibriosis is a bacterial disease responsible for mortality of cultured shrimp worldwide. Various studies has been done to find a remedy for vibriosis in rearing as well as shrimp culture ponds. Certain studies show that usage of microalgae, bacteriophage, and probiotic bacteria have been found to have higher potential in reducing vibriosis. Vibriosis is a series of bacterial infections caused by a bacterium belongs to the genus *Vibrio*. Black shell disease, bacterial septicemia,

hepatopancreatic necrosis, brown gill disease, swollen hindgut syndrome and luminous bacterial disease [1]. High density of the bacterial species in culture pond increases the probability of getting viral diseases, especially white spot syndrome

The pacific white shrimp (*Litopenaeus vannamei*), Indian white shrimp (*Fenneropenaeus indicus*), Black tiger shrimp (*Penaeus monodon)* are important commercial species of the penaeid family. *Fenneropenaeus indicus* supports commercial fisheries in both marine and brackish water environments on the east and west coasts of India. India is one of the major suppliers of shrimp to Japan, Europe, Thailand and USA [2]. The secondary infection of vibrios in *P. monodon* occurs due to poor water quality, stress, high stocking density, unstable environmental conditions, toxins and virion particles. Vibriosis is caused by a number of bacteria belongs to *vibrio* species which includes; *Vibrio harveyi, V. splendidus, V. parahaemolyticus, V. alginolyticus*. There have been occasional reports of vibriosis caused *by V. damsella, V. fluvalis* and other undefined *vibrio* species [3].

2. Vibrio diseases

2.1 Bacterial septicemia

This is one of the severe systemic diseases caused by bacteria, which affects shrimps and exhibits the symptoms such as lethargic, show abnormal swimming behavior, expansion of chromatophores, followed by reddish color change in the pleopods which can be seen in the abdominal musculature. In chronic cases, the gill covers appear flared up and eroded along with the melanized black blisters on the carapace and abdomen. The disease caused by *Vibrio alginolyticus, V. anguillarium or V. parahaemolyticus* and diagnosed based on gross signs like its swimming patterns, Food consumption ratio (FCR) and confirmed by analyzing the isolated pathogen from haemolymph or muscle sample by standard microbiological methods and histopathology. Bacterial septicemia can be prevented by maintaining good water quality and by reducing the organic load by increased water exchange. This can be prevented by giving high protein feed with antibiotics, repeated water exchange might help to decrease the density of disease causing pathogens [4].

2.2 Necrosis (Hepatopancreas, muscle and appendages)

Inflammation in the cells explores the proteins release from tissues and cells, which reflects on the color change of the animals as like milky white. This disease could be caused due to several unfavorable environmental conditions such as water quality, organic load, malnutrition and wastes producecd from the animals, in chronic cases, melanization of setae, antennae, appendages and muscle can be witnessed. Necrosis is usually caused by *Vibrio spp, Pseudomonas spp, Aeromonas spp* and *Flavobacterium spp* and can be diagnosed based on swimming patterns and other symptoms like white patches in cephalothorax and can be prevented by repeated water exchange and feeding nutrient rich feed. Necrosis is controlled by induced molting by applying 5–10 ppm fermented rice cake (**Figure 1**) [5].

3. Brown spot diseases: (Shell disease or rust disease)

This kind of disease in shrimps showed brown to black enodsed areas on the body surface and appendages, *Aeromonas spp*, and *Flavobacterium spp*., are the crucial causative agents involved in the pathogenisis through chitinolytic activity.



Figure 1.
Shrimps affected by Necrosis 1.

Major symptoms are stooped posture and brown to back spots on the exoskeleton, in extreme conditions it might even lead to necrosis [6]. Brown spot disease can be prevented by reducing organic load in water, with repeated water exchange and by feeding the shrimps with nutritional supplement.

3.1 Vibriosis in shrimp

Members of the microorganism genus *Vibrio* have become a major constraint on production and trading in shrimp industry. *Vibrio* is responsible for several diseases and causing mortalities up to 100 percent and global losses of around 4.5 billion USD. *Vibrio spp.* is a natural micro flora of wild and cultured shrimps, and become opportunistic pathogens when natural defense mechanisms are suppressed. In intensive



Figure 2.
Vibriosis in shrimp 1.

systems, crustaceans especially shrimps are often exposed to stressful conditions due to the high stocking density, leading to vibriosis [7]. *Vibrio* usually associated with etiological agents, however some vibrio species have been identified as primary pathogen. Several species of *vibrio* including *V. parahaemolyticus* and *V. harveyi* have been described as the main pathogenic species in shrimps (**Figure 2**) [8].

3.2 Filamentous bacterial disease

The disease was characterized by fouling of gills, setae, appendages and body surface. Molting is impaired and the larval shrimp may die due to stress and hypoxia, which is caused by filamentous bacteria such as *Leucothrix mucor*, which is diagnosed microscopically. This can be prevented by maintaining good water quality with optimal physical – chemical conditions controlled by 0.25–1 ppm copper sulphate bath treatment for 4–6 hours [9].

3.3 Factors responsible for disease outbreaks

- Unfavorable environment such as poor soil and water quality.
- Poor water exchange facilities with high stock density.
- Usage of poor quality feeds with low protein content.
- Accumulation of sludge in the pond bottom due to the presence of unutilized feed.
- Presence of gut micro flora and numerous virulent pathogens in the pond.

3.4 Disease controlling methods

3.4.1 Bacteriophage therapy

Bacteriophage therapy acts as a prophylactic alternative instead of antibiotics usage in shrimp industry. These are viruses that kill only specific disease causing pathogens and acts as therapeutic agents in pathogenic infections. Unlike antibiotics, bacteriophage therapy has no residual issues and has advantages of being specific to their host bacteria, without harming other micro-organisms [10]. In aquaculture hatcheries, bacterial diseases often cause considerable economic loss across globe for hatchery operators. Bacteriophages and their lytic enzymes are in use for therapy of bacterial infections in human and animals, as biocontrol agents for food protection also as tools in molecular biology, the penentration of phage DNA inside a bacteria is promoted by lysossome produced by the phage. In yellow tail fish, a pathogen named *Lactococcus garveyi* is inhibited by bacteriophage therapy in the early 1990s (**Figure 3**) [11].

3.4.2 Herbs as antibiotics

Herbs act as antibiotic for controlling or reduce the infection of pathogen in aquaculture sector and also increases the survival rate of organisms, during outbreak of disease managements. In *Fenneropeneaus indicus,* the *vibrio* disease controlled by garlic extract and hot water extracts of seaweeds *Sargassum sp* acts

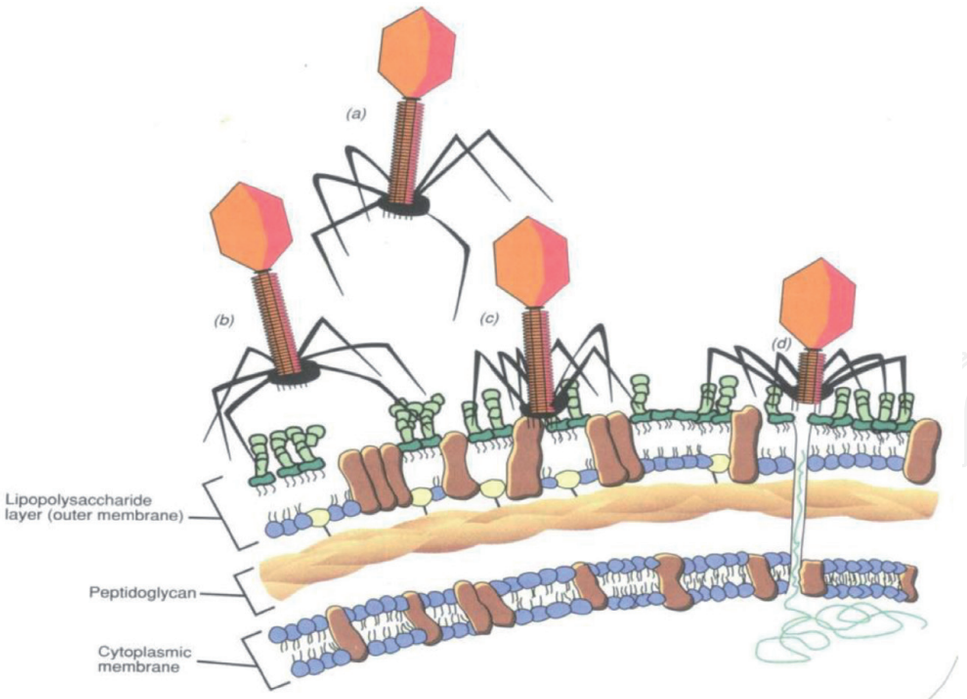


Figure 3.
Bacteriophage attached to bacterial cell 1.

as immunomodulator for white spot syndrome virus (WSSV) in shrimp *P. monodon*. Similarly, *Azardiracta indica* plant extract used as an ailment for *Citrobactor freundii* bacterial infection in *Oreochromis mosambicus* [12]. The majority of herbs act as anti-pathogenic agent, acts as antibiotic to strengthen the immune system of organisms prevent from disease or forming disease resistance variety in aquaculture sector.

3.4.3 Probiotics

Probiotics gaining more attention in recent scenario in all sectors including aquaculture, agriculture and animal husbandry when considering other remedies probiotics acts as a better option rather than incorporating antibiotics to control pathogens in aquaculture. The term probiotic has been defined as a mono or mixed culture of live microorganisms which can be applied to animal or human to enhance the immune system. The animal health is then improved by the removal or decrease in population density of pathogens and by improving water quality through more rapid degradation of waste organic matter (sludge). Environmental microbiology and biotechnology have advanced in the past decade, to the point that commercial products and technologies are available for treating large areas of water and land to enhance population densities of desired microbial species or biochemical activities. The practice of bioremediation is applied in many areas of interest, but success rate varies in different areas, depending on the environmental conditions, nature of products and the method of usage by the consumer, the probiotic that are added must be selected for specific functions. Bioaugmentation and the use of probiotics are significant tools for aquaculture but their efficiency depends on understanding the nature of competition between disease causing pathogens and desired strains of bacteria. *Bacillius* spp., *Lactobacillius* spp., *Pseudomonas* spp., nitrifying and denitrifying bacteria are some of the commonly used probiotic in shrimp culture.

3.4.4 Disease control

The disease control programmers in aquaculture must include examination of diseases and mortalities in a holistic manner and consider various factors such as stocking densities, environment (turbidity, temperature, pH, salinity, dissolved oxygen, H_2S,NH_3,NO_2, etc. of water and redox potential of soil), rate of water exchange, presence of toxic bottom dwelling algae, the type of feed and its FCR ratio by the shrimps, phytoplankton bloom, physiological status of shrimps, etc. [13]. Most of the disease control methods are based on preventive measures. They are,

- Better husbandry practices,
- Use of balanced nutritional supplement,
- Implementing nursery setup to avoid mortality in culture ponds,
- Use of GMO stocks for culture,
- Use of herbal extracts as antibiotics and
- Use of vaccines or drugs.

Diseases can be prevented by adapting better animal handling practices and providing adequate amount of nutrient rich feed [14]. Vibriosis is controlled by rigorous water management through ROS systems and sanitation to prevent the entry of vibrio in the culture water and to reduce stress on the shrimps. Good site selection, pond design and pond preparation are also important. An increase in daily water exchanges and a reduction in pond biomass by partial harvesting are recommended to reduce mortalities caused by Vibriosis. Draining, drying and administering lime/dolomite to ponds following harvest is also recommended [15].

4. Conclusion

In spite of all these recent advancements to eradicate all the bacterial diseases in shrimps, still there is a void for complete eradication of these diseases. Various techniques and medicines are introduced to cure these bacterial infections, but still there are certain side effects for consumers, by introducing antibiotics and other medicines for respective infections. So when it comes to large scale like commercial farming, the efficacy of the above mentioned techniques for prevention and cure of cultured shrimps from bacterial diseases is low when compared to laboratory conditions.

DOI: http://dx.doi.org/10.5772/intechopen.97018

IntechOpen

Author details

Hethesh Chellapandian[1], Jeyachandran Sivakamavalli[1]*, A. Vijay Anand[2] and Balamuralikrishnan Balasubramanian[3]

1 Department of Biotechnology and Microbiology, National College, Tiruchirappalli, Tamilnadu, India

2 Department of Human Genetics and Molecular Biology, Bharathiyar University, Coimbatore, Tamilnadu, India

3 Department of Food Science and Biotechnology, College of Life Science, Sejong University, Seoul, South Korea

*Address all correspondence to: drjsvalli@nct.ac.in

IntechOpen

© 2021 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. CC BY

References

[1] Jeyachandran S, Park K, Kwak I-S. Bacterial Disease Control Methods in Shrimp Farming Sector. Yeosu 59626, South Korea: Fisheries Science Institute, Chonnam National University

[2] Olafsen. Interaction between fish larvae and bacteria in marine aquaculture. 2001

[3] Lo C-F, Lee C-T, et al. The opportunistic marine pathogen *Vibrio parahaemolyticus* becomes virulent by acquiring a plasmid that expresses a deadly toxin. 2015

[4] Chen Y-Y, Chen J-C, Tseng K-C, Lin Y-C, Huang C-L. Activation of Immunity, Immune Response, Antioxidant Ability, and Resistance against *Vibrio alginolyticus* in White Shrimp *Litopenaeus vannamei* Decrease under Long-term Culture at Low pH. Keelung 202, Taiwan, ROC: Department of Aquaculture, National Taiwan Ocean University; 2015

[5] Chandrakala N, Priya S. Vibriosis in Shrimp Aquaculture A Review. Thanjavur, Tamilnadu, India: PG & Research Department of Zoology, Kundhavai Naacchiyaar Govt Arts College For Women(A); 2017

[6] Alavandi S, Vijayan K, Santiago T, Poornima M, Jithendran K, Ali S, et al. Evaluation of Pseudomonas sp.PM11 and Vibrio fluvialis PM17 on immune indices of tiger shrimp, Penaeus monodon. 2004

[7] Dash P, Avunje S, Tandel RS, Sandeep KP, Panigrahi A. Biocontrol of luminous vibriosis in shrimp aquaculture: A review of current approaches and future perspectives. 2017

[8] Hsu S, Chen J. The immune response of white shrimp *Penaeus vannamei* and its susceptibility to *Vibrio alginolyticus* under sulfide stress. 2007

[9] Rengpipat S, Tunyanun A, Fast AW, Piyatiratitivorakul S, Menasveta P. Enhanced growth and resistance to *Vibrio* challenge in pond-reared black tiger shrimp *Penaeus monodon* fed a Bacillus probiotic. 2003

[10] Culot A, Grosset N, Gautier M. Overcoming the challenges of phage therapy for industrial aquaculture: A review. 2019

[11] Abdul Hannan MD, Mahbubur Rahman MD, Nurunnabi Mondal MD, Suzan Chandra DEB, Chowdhury G, Tofazzal Islam MD. Molecular identification of Vibrio alginolyticus causing Vibriosis in shrimp and its Herbal remedy.

[12] Yasin IA, Hashizume A, Ido A, Takahashi T, Miura C, Miura T. Establishment of challenges study system for vibriosis of Japanese tiger prawn (*Marsupenaeus japonicus*) with a pathogenic *Vibrio penaeicida* strain. 2017

[13] Pérez-Sánchez T, Mora-Sánchez B, Luis Balcázar J. Biological approaches for disease control in aquaculture: Advantages, limitations and challenges. 2018

[14] Domínguez-Borbora C, Ardilesa V, Bermeoa M, Bolívar-Alvaradoa C, Tomaláa C, Sonnenholznera S, et al. The marine symbiont *Pseudovibrio denitrificans*, is effective to control pathogenic *Vibrio* spp. in shrimp aquaculture. 2019

[15] Hsu C-H, Chen J-C, Lin Y-C, Chen Y-Y, Liu P-C, Lin B-W, et al. White shrimp *Litopenaeus vannamei* that have received mixtures of heat-killed and formalin-inactivated *Vibrio alginolyticus* and *V. harveyi* exhibit recall memory and show increased phagocytosis and resistance to Vibrio infection. 2020

Preetham Elumalai
Sreeja Lakshmi *Editors*

Functional Foods and Therapeutic Strategies for Neurodegenerative Disorders

Springer

Functional Foods and Therapeutic Strategies for Neurodegenerative Disorders

Preetham Elumalai • Sreeja Lakshmi
Editors

Functional Foods and Therapeutic Strategies for Neurodegenerative Disorders

Springer

Editors
Dr. Preetham Elumalai
Department of Marine Biology, Microbiology and Biochemistry
School of Marine Sciences, Cochin University of Science and Technology
Cochin, Kerala, India

Dr. Sreeja Lakshmi
School of Ocean Science and Technology, Kerala University of Fisheries and Ocean Studies
Cochin, Kerala, India

ISBN 978-981-16-6702-2 ISBN 978-981-16-6703-9 (eBook)
https://doi.org/10.1007/978-981-16-6703-9

© The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature Singapore Pte Ltd. 2022
This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors, and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Preface

Aging is an inevitable phenomenon creating entropy in one's life by deteriorating one's physiological systems and anatomical structures. Senescence is associated with increased risk for a plethora of diseases and some of them end up with loss of homeostasis and finally death. As age progresses many of the biological processes as well as environmental factors conjointly lead to progressive neurodegeneration. Neurodegeneration is an inherent condition characterised by structural and functional impairment of neurons. The most prevalent neurodegenerative disorders—Alzheimer's disease (AD), Parkinson's disease (PD), Huntington's disease (HD), and Amyotrophic lateral sclerosis (ALS)—are often hired as life threatening as well as a social and economic burden to the healthcare system. Despite the conventional beliefs and strategies, science along with the healthcare system has taken initiatives to step forward with healthy aging for better living of aged people. Past few year's scientific research has explored novel remedies, incorporating diet, lifestyle factors, and bioactive compounds/immunostimulants from natural resources to treat neurodegenerative disorders in the context where therapeutic drugs were found ineffective in reverting or pausing neurodegenerative disorders. Moreover, these natural antidotes are depicted as highlighters that boons the sustainability of healthy brain rendering protection against neurodegeneration.

Our book is anticipated to provide an overview of the current status of research and future perspectives in the field of treating neurodegenerative disorders. The book will integrate different aspects such as advancements in current treatment scenario incorporating prebiotics, phytochemicals, polyphenols and potential marine bioactive compounds towards the treatment strategies along with leading contemporary methods for prophylactic and diagnostic practices, comprising nanoparticles, in silico techniques and biomarkers. We expect that the contents of the book provide potential knowledge regarding future perspectives in the management of neurodegenerative disorders.

Cochin, Kerala, India

Preetham Elumalai
Sreeja Lakshmi

Contents

Part I Understanding Aging

1 **Aging and Neurodegeneration: A Preface** 3
Sreeja Lakshmi

Part II Neurodegenerative Disorders: Underpinning Mechanisms

2 **Deciphering the Molecular and Genetic Basis of Alzheimer's Disease** 13
Shamprasd Varija Raghu and Avinash Kundadka Kudva

3 **Tracking Neurodegeneration: Advancement in Experimental Study Models** 25
Murugesan Arumugam and S. Sugin Lal Jabaris

Part III Treating Neurodegenerative Disorders: Natural Remedies

4 **Pharmacological Application of *Phyllanthus emblica* as Therapeutics in Alzheimer's Disease** 51
Avinash Kundadka Kudva, Manjeshwar Shrinath Baliga, and Shamprasad Varija Raghu

5 **Role of the Gut Microbiome and Its Modulation in Neurodegenerative Diseases** 65
Preeja Prabhakar and Sivaprasad Punnaveetil

6 **Recent Advances in Application of Dietary Polyphenols to Treat Age-Related Neurological Disorders** 79
Prachi Vibhute, Akshaya Radhakrishnan, and Jeyachandran Sivakamavalli

7 **Prophylaxis Through Marine-Derived Bioactive Compounds Toward Neurodegenerative Disorders** 101
Abdullah Bin Abdul Nazar, K. A. Adhila Beegam, Aneetta Skinner, Debarghya Ghosh Dastidar, Emmanuel Joseph Antony, B. R. Malavika, Muzammil Siddiqui, Rinsa Mol, and Preetham Elumalai

8 **Recent Advancements in Omega Fatty Acids to Treat Neurodegeneration** 121
Neha Omgy, B. Anjana, V. Anusree, K. K. Annmary, and Sreeja Lakshmi

9 **Role of Alkoxyglycerol to Pause Tau-Induced Alzheimer's Disease** 139
Anuj Sharma, Sanchu Prakash, S. Muhammed Salih, Priya Maria Vinesh, Pragati Kumari, Sreeja Lakshmi, and Preetham Elumalai

Part IV Perspectives with Developmental Strategies

10 **Application and Efficacy of Nanoparticle-Based Therapy Among Neurodegenerative Diseases** 163
M. Vijay Kumar and Kartik Bhairu Khot

11 **In Silico Techniques: Powerful Tool for the Development of Therapeutics** 177
Kizhakke P. Anupama, Anet Antony, Olakkaran Shilpa, and Hunasanahally P. Gurushankara

12 **Biomarkers: Potential Perspectives in Detection, Diagnosis, and Prognosis of Neurodegenerative Disorders** 203
H. P. Chethana, Gauthami Hemachandra, and Arshdeep Sidhu

Chapter 6
Recent Advances in Application of Dietary Polyphenols to Treat Age-Related Neurological Disorders

Prachi Vibhute, Akshaya Radhakrishnan, and Jeyachandran Sivakamavalli

Abstract One of the main causes of synaptic damage and impaired neural transmission in numerous neurodegenerative disorders is the progressive buildup of misfolded amyloid proteins in intracellular and extracellular areas. Effective therapies for these illnesses are still unavailable, although they are nevertheless the subject of intense research. Despite decades of study, just a few synthetic chemicals, small molecules, and medicines have been found to prevent amyloid protein aggregation and reduce their neurotoxic effects. Antioxidants, particularly those derived from food, have been proposed as potential medicines for the prevention and treatment of Alzheimer's disease in recent years. Polyphenols are known to lower the risk of neurological disorders such as Alzheimer's disease (AD), stroke, multiple sclerosis (MS), Parkinson's disease (PD), and Huntington's disease (HD) through reducing oxidative stress. Polyphenols have the ability to address the genesis of neurological diseases by attenuating their complicated physiology by simultaneously regulating several therapeutic targets. Several research published in recent years aimed to verify sensitive and reliable translational techniques for mechanistically characterizing brain bioavailable polyphenols as disease-modifying drugs to help prevent the onset of Alzheimer's disease and other neurodegenerative disorders. Several research groups from around the globe with expert knowledge in Alzheimer's disease, plant biology, nutritional sciences, and botanical sciences have published high-quality study results that have finally provided the necessary evidence that polyphenols and their metabolites, which can be found in a variety of foods, can help to prevent Alzheimer's disease. The studies mentioned in this review article back up the findings of recent research that have had a significant influence on neurodegenerative disorders by giving crucial information on polyphenols' protective functions. Despite the fact that current polyphenol research has had minimal influence on clinical practice, there is significant evidence and testable hypothesis that they can contribute to therapeutic advancements and therapeutic discovery in the field of age-related neurological diseases.

P. Vibhute · A. Radhakrishnan · J. Sivakamavalli (✉)
PG & Research Department of Biotechnology & Microbiology, National College, Tiruchirappalli, Tamil Nadu, India
e-mail: drjsvalli@nct.ac.in

© The Author(s), under exclusive license to Springer Nature Singapore Pte Ltd. 2022

P. Elumalai, S. Lakshmi (eds.), *Functional Foods and Therapeutic Strategies for Neurodegenerative Disorders*, https://doi.org/10.1007/978-981-16-6703-9_6

Keywords Polyphenols · Neurodegenerative disease · Alzheimer's disease · Multiple sclerosis · Parkinson's disease

Abbreviations

AD	Alzheimer's disease
BDPP	Bioactive dietary polyphenol preparation
EGCG	Epigallocatechin-3 gallate
GPx	Glutathione peroxidase
GR	Glutathione reductase
HD	Huntington's disease
JNK	c-Jun N-terminal kinase
MAPK	Mitogen-activated protein kinase
MCI	Mild cognitive impairment
MS	Multiple sclerosis
NFkB	Nuclear factor kappa-light-chain-enhancer of activated B cells
PD	Parkinson's disease
Syn	α-Synuclein

6.1 Introduction

Alzheimer's disease, Parkinson's disease, multiple sclerosis, Huntington's disease, and other neurodegenerative illnesses are only a few examples. Because their instances are sporadic, determining the cause of these diseases and preventing them are difficult. Many neurological disorders and age-related degenerative processes have been linked to oxidative stress. Neurodegenerative disorders have a complicated etiology involving a complex combination of hereditary and environmental variables. The bulk of these instances are of an environmental or sporadic nature. The most prevalent neurodegenerative illnesses are Alzheimer's disease (AD) and Parkinson's disease (PD). They are complex, progressive, age-related, and genetically and environmentally affected. Despite the fact that they are public health issues that have been extensively researched, there are no viable remedies. Currently, treatments are only symptomatic and aimed at improving patients' quality of life (Przedborski et al. 2003). Furthermore, there are no diagnostic techniques for early diagnosis of these illnesses, which share several clinical characteristics, particularly at the start. Specific proteins have been linked to the diseases, but it is unknown when and how they lose their function and become abnormal and toxic. Several routes of cellular malfunction have been put forward to explain the disease toxicity; however, the pathological significance of the proteins implicated is still debated. Personalized therapies and targeted medicines are by far the most efficient treatment methods. Alternative pharmacological therapies and natural compounds,

particularly those linked with the Mediterranean diet, such as polyphenols, have sparked fresh attention in the recent decade. Polyphenols' surprising advantages and broad range of characteristics imply that further research is needed to have a better understanding of their mechanism of action and to employ them in further successful treatments (Bagetta et al. 2020).

Because it uses so much oxygen for energy and has so few antioxidant defense enzymes, the brain is particularly sensitive to oxidative damage, especially as it ages. Furthermore, the membranes of brain cells contain very high levels of polyunsaturated fatty acids (PUFAs). Neurons are particularly prone to toxic chemicals and to damage caused by ischemia/stroke, seizures, and other excitotoxic injuries among the many kinds of brain cells (Milatovic et al. 2009). Lipid peroxidation (oxidative damage to lipids) is linked to a gradual loss of membrane integrity, a decrease in mitochondrial membrane potential, and an increase in plasma membrane permeability to Ca^{2+}. Carbonyl and nitrosylated derivatives are formed when proteins are damaged by oxidation. In addition, ROS damage to DNA causes nuclear condensation and changes in gene expression. Different reactive oxygen species (ROS), such as superoxide, hydrogen peroxide, and hydroxyl and peroxyl radicals, are generated in cells under normal and pathological circumstances, according to research (Valls et al. 2005). Oxidative damage to DNA, proteins, and lipids occurs when the rate of ROS production surpasses the capability of antioxidant defense. Oxidative stress has been linked to neuronal cell damage in the central nervous system (CNS) in a variety of disease conditions. The term "nitrosative stress" has lately been coined to describe cellular damage caused by reactive nitrogen species (RNS), which would include nitric oxide (NO) and its derivative products such as peroxynitrite and nitroxyl anion (Klatt and Lamas 2000). Oxidative and nitrosative stresses are both involved in the pathology of many neurodegenerative disorders, including Alzheimer's disease (AD), Parkinson's disease (PD), and Huntington's disease (HD).

In in vitro and in vivo models of neurodegeneration, many antioxidant substances produced from natural products (nutraceuticals) have shown neuroprotective effects: (1) flavonoid polyphenols, such as epigallocatechin 3-gallate (EGCG) and quercetin; (2) non-flavonoid polyphenols, such as curcumin and resveratrol; (3) phenolic acids or phenolic diterpenes, such as rosmarinic acid or carnosic acid; and (4) organosulfur compounds, such as isothiocyanate, L-sulforaphane, and thiosulfinate (allicin) (Kelsey et al. 2010). They directly scavenge free radicals or indirectly boost endogenous antioxidant defenses by activating the nuclear factor erythroid-derived 2-related factor 2 (Nrf2) transcription factor pathways, for example. The intrinsic free radical scavenging activities of these nutraceutical antioxidants suggest that they may have potential utility in mitigating neuronal oxidative stress and neurodegeneration as shown in the Fig. 6.1. Other mechanisms of action of these compounds include modulation of signal transduction cascades or effect on gene expression (Tuñón et al. 2009). The following sections will be discussing the mechanism of action of polyphenols to help in treating neurodegenerative disorders.

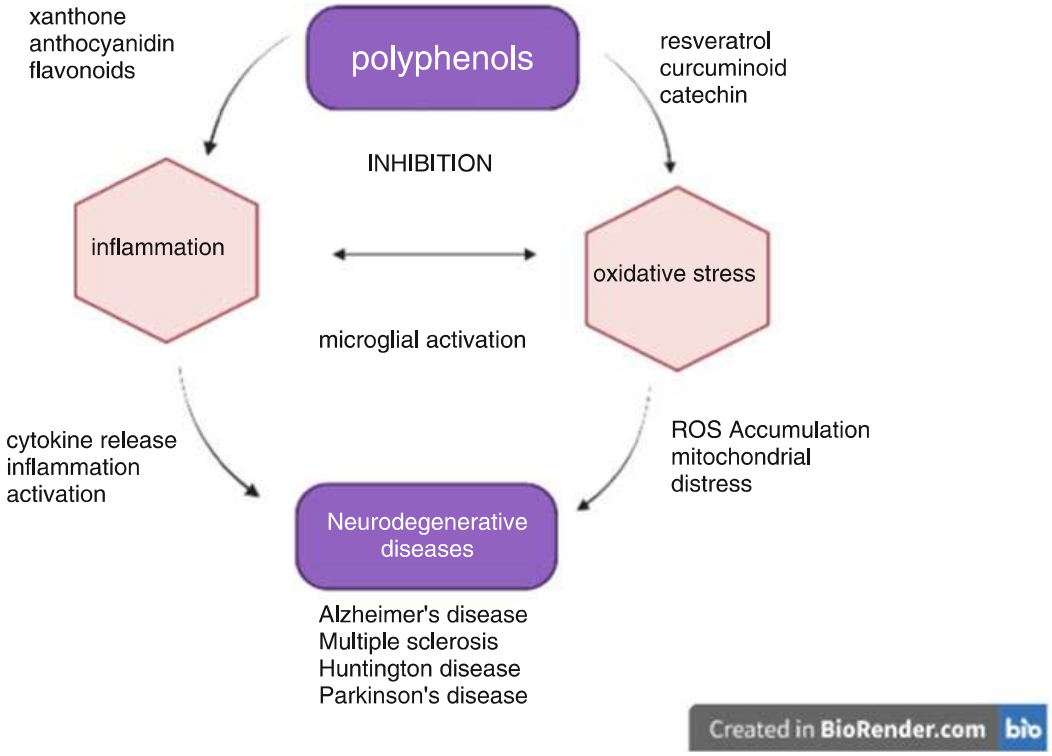


Fig. 6.1 Role of polyphenols in neurodegenerative disease treatment

6.2 Introduction to Neurodegenerative Disorders

6.2.1 Alzheimer's Disease (AD)

Alzheimer's disease is marked by a progressive decrease of cognitive function, memory loss, and behavioral abnormalities. A synaptic deficiency in the neocortex and limbic system, neuronal loss, white matter loss, astrogliosis, microglial cell proliferation, and oxidative stress are all common symptoms of the illness. The appearance of intracellular flame-shaped neurofibrillary tangles with extracellular plaques in the brain is a pathological marker of Alzheimer's disease (Stutzmann 2007). The Tau protein, in a hyperphosphorylated state, is the most common cause of tangle formation in the perinuclear cytoplasm. The plaques are caused by the accumulation of amyloid-β-peptide (Aβ) in a filamentous form throughout time. The neuritic plaques range in size from 10 to more than 120 μm in diameter. The procedures for determining the pathology's diagnostics have been standardized. The number and degree of compactness of neuritis amyloid plaques and neurofibrillary tangles are discussed. As a result of their location and development, AD aggregates can be categorized as positive or negative lesions. Amyloid plaques and neurofibrillary tangles, neuropil threads, and dystrophic neurites, all of which are fundamentally generated by hyperphosphorylated Tau, are typical positive lesions. Neurons and neuropil threads are lost in the negative lesions (Selkoe 1991).

6.2.2 Parkinson's Disease (PD)

Motor symptoms such as bradykinesia, stiffness, resting tremor, and instability are common in people with Parkinson's disease. Because there is no conclusive test for the diagnosis of Parkinson's disease, the emergence of these clinical symptoms is critical for the illness's early treatment. The loss of dopaminergic neurons in the *Substantia nigra pars compacta* and the deposition of intraneuronal proteinaceous clumps, primarily formed of α-synuclein (Syn), known as Lewy bodies and Lewy neurites, are hallmarks of Parkinson's disease (Taylor and Saintcyr 1995). Syn was also discovered in the Lewy body form of Alzheimer's disease and multiple system atrophy pathological inclusions. Syn inclusions are also seen in other neurodegenerative illnesses known as synucleinopathies, including Down's syndrome, progressive autonomic failure, and familial and sporadic Alzheimer's disease. Shahmoradian and colleagues have shown that Lewy bodies are produced not only by Syn deposits but also by clusters of lipid vesicles. These significant findings show a link between Syn–lipid interaction and neurodegeneration (Halliday and McCann 2010).

6.2.3 Multiple Sclerosis (MS)

MS is a systemic illness that affects the central nervous system's gray and white matter. Inflammatory and degenerative mechanisms occur simultaneously, and the balance between them determines whether the illness is relapsing–remitting or progressive. It is unclear if basic progressive MS is a distinct disease entity or just a disease phenotype without high-grade inflammatory processes. The same dilemma applies to very active MS patients with tumefactive lesions, and the question is if there is a molecular key that defines whether an immune response is overwhelming or subtle (Stadelmann 2011). The existence of localized white matter lesions, characterized by initial demyelination with partial preservation of axons and reactive astrocytic scar formation, was originally used to describe its pathophysiology. Although, in comparison to full demyelination, axons are relatively well maintained inside the lesions, they are nonetheless damaged, and axonal loss has been proven to be a key predictor of persistent neurological impairment in MS patients. When patients have clinical relapses and remissions in the early stages of the disease, inflammatory demyelination causes localized plaques to develop, which are mostly seen in the white matter. Additional pathology is found in later stages of the disease, especially in individuals with secondary or main progressive disease, such as extensive demyelination in the cerebral and cerebellar cortex, as well as diffuse degenerative alterations throughout the white and gray matter (Lassmann 2018). Patients with long-term severe illness eventually have significant brain and spinal cord atrophy, as well as widespread tissue loss and cerebral ventricle dilation. While the illness begins with inflammatory-driven localized demyelinating lesions that

develop around tiny drainage veins in the white matter, it eventually progresses to widespread neurodegeneration that affects the whole CNS (Lassmann et al. 2012).

6.2.4 *Huntington's Disease (HD)*

Huntington's disease (HD) is a neurological illness that causes mobility problems, cognitive decline, and mental symptoms. A (CAG)n trinucleotide repeat expansion near the 5′ end of a gene that codes for the huntingtin protein causes it as listed in the Table 6.1 (van der Burg et al. 2009). The repetitions induce illness by providing a new detrimental function on huntingtin, which is translated into an abnormally enlarged polyglutamine tract. The pathophysiology of HD is characterized by the neuronal loss that is selective, with the striatum and deeper layers of the cerebral cortex suffering the most. The development of intraneuronal inclusions or aggregates is linked to the illness. With a clinical course of >15–20 years, HD causes catastrophic brain atrophy and death (Vonsattel and DiFiglia 1998). The striatal medium spiny neurons (MSNs) of the brain appear to be particularly susceptible in HD, while other brain areas may also be impacted. GABAergic MSNs are found in the striatum and project to the substantia nigra (striatonigral) and globus pallidus (striatopallidal). Even though the specific causes for this selective susceptibility and loss of striatal MSNs are unknown, it has been observed that HD patients lose around 88% of their striatal neurons as compared to healthy persons (Holley et al. 2018).

6.3 Introduction to Polyphenols

Polyphenols are substances having at least two hydroxyl groups linked to one or more phenyl rings. Thousands of polyphenolic compounds exist in plants, each with several alternative double bonds, hydroxyl groups, and more than one phenyl ring.

Table 6.1 Age-associated neurodegenerative diseases and their associated protein

Disease.	Affected region	Protein aggregated	Deposition	References
Alzheimer's disease	Cerebral cortex, hippocampus	Amyloid-beta, tau	Intracellular tangles and extracellular plaques	Selkoe (1991)
Huntington's disease	Striatum, cerebral cortex	Huntingtin	Intracellular nuclear inclusions	Ghosh and Tabrizi (2018)
Parkinson's disease	Substantia nigra	Alpha-synuclein	Intracellular cytoplasmic inclusions	Taylor and Saintcyr (1995)
Multiple sclerosis	CNS: Gray and white matter	Amyloid precursor, tau	Cerebrospinal fluid lesions and plaques	Stadelmann (2011)

Table 6.2 Major polyphenols and their characteristics (Han et al. 2007)

Polyphenols	Dietary form	Chemical nature	Source of availability
Flavanols	Catechin, epicatechin EGCG	Methyl sulfate conjugates; EGCG in unconjugated forms	Teas, apple pears, chocolate
Curcuminoid	Curcumin	Desmethoxycurcumin, bismethoxycurcumin	Turmeric
Anthocyanidins	Cyanidin, malvidin	Glucosides	Red, blue, purple berries
Stilbene	Resveratrol	Glucuronides, sulfate conjugates	Purple grape, redwine, peanut
Dihydrochalcone	Aspalathin	2,3,4,4-pentahydroxy-3-C-β-d-glucopyranosyl dihydrochalcone	Legumes
Xanthones	Xanthones, mangiferin, and isomangiferin	Tricyclic aromatic system	Honeybush tea

Anthocyanins, flavanols, flavones, isoflavones, stilbenes, and lignans are only a few examples of plant-derived polyphenols (Scalbert et al. 2005). Polyphenols are secondary metabolites that are considered to protect plants from radiation, infections, and other stresses. In edible plant components such as fruit, leaf, stem, root, and seed, over 500 polyphenolic chemicals have been discovered of which, major are listed in the Table 6.2. Preclinical, clinical, and epidemiological research shows that a plant-based diet, with a concentration on fruits and vegetables, decreases the risk of neurodegenerative disorders substantially. Polyphenolic chemicals found in edible plants are a vital class of micronutrients that contribute to the health advantages of a diet rich in fruits and vegetables (Dai and Mumper 2010). Polyphenols have a lot of antioxidant characteristics, including the capacity to scavenge free radicals and boost the production of antioxidant enzymes, according to a lot of data. Polyphenols have also been demonstrated to reduce the production of pro-inflammatory cytokines and inhibit the inflammatory cascade. Dietary polyphenols' antioxidant and anti-inflammatory properties lower tissue damage risk and contribute to health benefits in age-related chronic illnesses (Oliviero et al. 2018). Polyphenols have been shown to affect cellular signaling mechanisms and signal transduction pathways associated with oxidative stress, redox modulation, the inflammatory cascade, cell proliferation and migration, and a variety of other processes linked to the pathogenesis and progression of chronic diseases (Kang et al. 2019). Several important dietary polyphenols have been studied in preclinical in vitro and in vivo models of chronic illnesses during the last decade. Green tea catechins and blacktea theaflavins (found in green tea and black tea), curcuminoids (found in the curry spice turmeric), anthocyanins (found primarily in berries), and resveratrol (found in red wine, grapes, and peanuts) have all been studied for their therapeutic potential in the treatment of age-related chronic diseases (Hano and Tungmunnithum 2020).

6.3.1 Tea Polyphenols

After water, tea, made from the leaves of the *Camellia sinensis* plant, is the most frequently consumed beverage on the planet. The main difference between white, green, oolong, and black teas is the degree of processing throughout the production process, which largely consists of drying and fermenting. The most significant polyphenols in tea are catechins and theaflavins, whose amounts vary according to the degree of oxidative fermentation (Xing et al. 2019). Catechins are found in the greatest concentrations in nonfermented white and green teas, which dimerize to create theaflavins when oxidized. Black tea, which is made by fermenting tea leaves, is high in theaflavins, which are orange-red pigments that give it its color. Oolong tea is a hybrid of green and black teas that have been partially fermented (Kamat et al. 2008). Along with other catechins and theaflavins, epigallocatechin-3 gallate (EGCG), the most famous and well-known tea polyphenol, has been widely investigated in preclinical models of chronic illness and clinical trials. EGCG and other tea polyphenols have been found to have potent antioxidant and anti-inflammatory properties, as well as modulatory action for a variety of disease progression signaling pathways (Williams et al. 2004).

6.3.2 Curcuminoids

Turmeric is a rhizome (*Curcuma longa*) that grows in tropical South Asia and is also known as "Indian saffron." Turmeric's therapeutic properties are owed to the intensely yellow curcuminoid polyphenols curcumin, desmethoxycurcumin, and bisdesmethoxycurcumin, which have shown therapeutic potential in a variety of age-related chronic ailments, including autoimmune, cardiovascular, cancer, and neurodegenerative diseases, such as Alzheimer's and Parkinson's disease (Sharma et al. 2005). Curcumin, the main curcuminoid found in turmeric, is one of the most researched dietary compounds, with strong antioxidant and anti-inflammatory effects as well as the capacity to influence a variety of signaling pathways (Tønnesen and Karlsen 1985).

6.3.3 Anthocyanins

Anthocyanins are a category of water-soluble pigments found in a variety of flowers, fruits, and vegetables. They are present in large amounts in several popular berry fruits of the genus *Vaccinium*, as well as many other genera such as bilberry, blackberry, blueberry, cranberry, lingonberry, mulberry, raspberry, and strawberry, as well as cherries and currants, and are responsible for the blue and purple color of berries. Pomegranate (*Punica granatum*), a "wonder fruit," and chocolate both

contain anthocyanins (Francis 1982). Among the most frequent dietary anthocyanins are cyanidin, delphinidin, malvidin, peonidin, pelargonidin, and petunidin, to name a few. Many epidemiological studies have highlighted the health advantages of anthocyanin-rich dietary components, whose potent antioxidant, anti-inflammatory, and therapeutic activities have recently been studied (Farzaei et al. 2018).

6.3.4 Resveratrol

Resveratrol, a stilbene polyphenol found in several dietary and nondietary plant sources, is classified as a phytoalexin, synthesized in response to bacterial and fungal attack. Resveratrol is also produced in response to several environmental stresses, including ultraviolet (UV) radiation (Tian and Liu 2020). Some of the major dietary sources of resveratrol are berries, grapes, red wine, and peanuts. Resveratrol is a widely studied molecule and is most well known as the agent responsible for the "French paradox": a phenomenon whereby the consumption of red wine is suggested as the reason why the French suffer from a comparatively low incidence of cardiovascular disease despite having a diet rich in saturated fats (Darvesh et al. 2017). Resveratrol is a strong antioxidant and anti-inflammatory drug that has been proven to extend longevity in preclinical and clinical trials in a variety of oxidative stress and inflammation-related illnesses, including cancer, cardiovascular disease, infections, and neurological diseases (Das and Das 2007).

6.3.5 Dihydrochalcones

The plant Rooibos (*Aspalathus linearis*) belongs to the legume family and is only found in a tiny area of South Africa's Western Cape. Its dried and fermented leaves and twigs are used to produce herbal tea, which has been popular in the area for generations and is now exported and enjoyed worldwide (Street and Prinsloo 2013). The dihydrochalcones aspalathin (2,3,4,4-pentahydroxy-3-C-β-d-glucopyranosyl dihydrochalcone) and its structural homolog nothofagin are responsible for rooibos' antioxidant action (differing only in that it lacks the A ring catechol group) (Snijman et al. 2009). Using the thiobarbituric acid reactive substances (TBARS) test, Inanami et al. investigated the effect of long-term (>20 months) administration of rooibos extract on lipid peroxidation in the rat brain. Increased lipid peroxidation is significantly linked to AD and aging in humans, as previously mentioned. Lipid peroxides were found to be substantially greater in the frontal and occipital cortex, the hippocampus, and the cerebellum of control groups of 24-month-old rats compared to juveniles in a research study by Inanami and coworkers (aged 5 weeks). Surprisingly, the signal intensities for age-related markers in the frontal cortex, hippocampus, and cerebellum of rooibos-treated rats matched those of 5-week-old rats in an additional MRI study by the same authors, but the same areas in untreated 24-month-

old rats showed significant age and lipid peroxidation-related elevation of these markers (Darvesh et al. 2010). As a result, these researchers conclude that age-related accumulation of lipid peroxides in the brain, which was closely correlated with morphological changes seen on MRI, revealed that chronic rooibos administration prevented age-related accumulation of lipid peroxides in several regions of the rat brain (Inanami et al. 1995).

6.3.6 Xanthones

The genus *Cyclopia* includes a number of shrubs native to the Cape Fynbos area of South Africa, the most common of which is *Cyclopia intermedia,* often known as the honeybush shrub. Honeybush herbal tea, which is extensively drunk in South Africa, has been made from this plant for decades (McKay and Blumberg 2007). The honeybush has yielded many polyphenols, including the xanthones mangiferin and isomangiferin, as well as the flavanones hesperidin and eriocitrin. Mangiferin has been the most extensively investigated of these substances in paradigms relating to the underlying pathophysiological processes of Alzheimer's disease. Mangiferin protected mouse brain against oxidative damage caused by 12-O-tetradecanoylphorbol-13-acetate (TPA), according to Sánchez et al. In addition, when compared to TPA controls, mangiferin provided significant (22%) protection against DNA fragmentation in the brain and reduced lipid peroxidation in brain homogenates by 39% (Matkowski et al. 2013). Gottlieb et al. found that in the presence of submicromolar quantities of mangiferin, neuronal cell death caused by glutamate in in vitro cell cultures was reduced. Receptor-mediated calcium influx was reduced, oxidative stress was reduced, and apoptosis was significantly reduced in these cultures (Gottlieb et al. 2006).

6.4 Polyphenols and Neurodegeneration

6.4.1 Neuroprotective Activity

NDs are a diverse set of diseases defined by post-mitotic neuronal cell malfunction and/or gradual loss in the central or peripheral nervous systems. Cognitive decline, dementia, motor irregularities, sleep problems, and behavioral and psychiatric disorders are the most common clinical manifestations of neurodegeneration. The buildup of aberrant, misfolded, and aggregated proteins; mitochondrial dysfunction; inflammation; oxidative stress accumulation; improper neural transport; impairment of the autophagic process; and change in proteasome activity are all prevalent cellular and molecular processes in NDs. NDs are incurable, progressive, and highly debilitating illnesses that pose a major burden in terms of human suffering and healthcare expenditures. The challenge for physicians and researchers is to develop

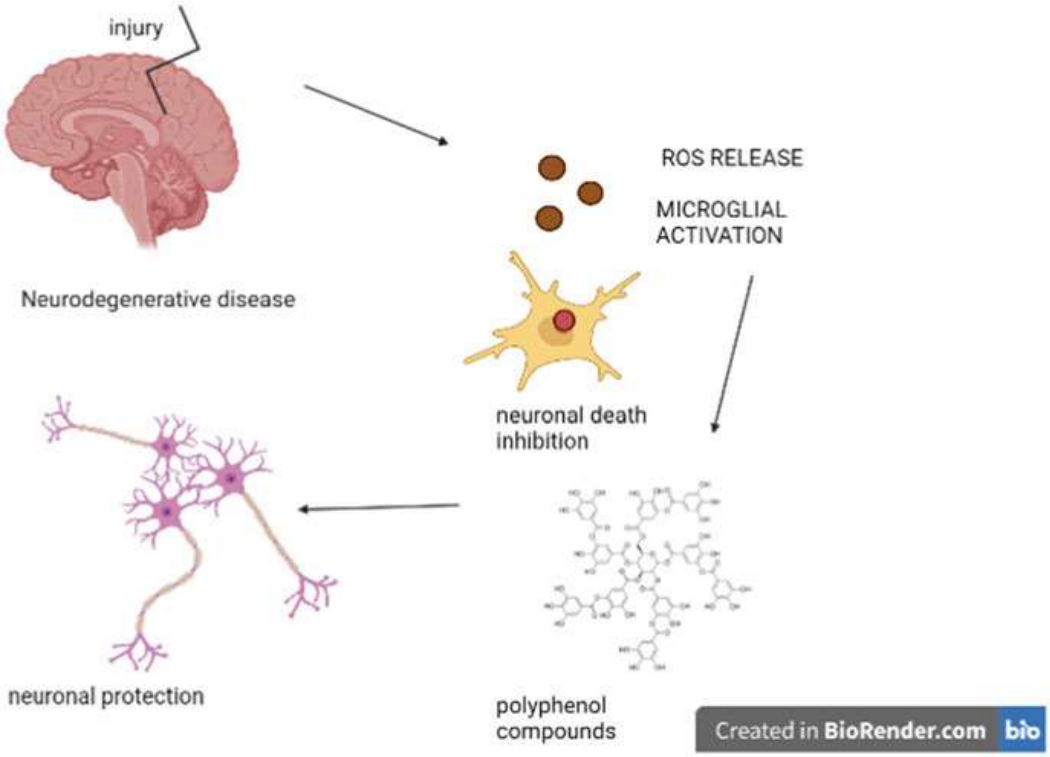


Fig. 6.2 Neuroprotective mechanism of dietary polyphenols

new medications to slow down neurodegeneration and enhance their patients' quality of life due to a lack of effective treatments. Increased cellular oxidative stress plays a significant part in the main etiologies of NDs, in addition to risk factors such as genetics and environmental influences (Tsuji 2002). Polyphenol consumption in the diet has been shown to reduce cellular oxidative stress and is a viable method for ND prevention. Polyphenols inhibit free radical damage by interacting with the hypoxia-inducible factor 1-alpha (HIF-1α) pathway, modifying production of protective genes against oxidative stress, regulating ROS via engaging with oxidative pathways, and scavenging metal ions. Metal ions (Fe^{2+}, ZN^{2+}, Cu^{2+}) accumulate in certain brain areas of ND patients, causing oxidative stress, which can be chelated by a wide range of polyphenols as shown in the Fig. 6.2. These chemicals, for example, appear to work by complexing transition divalent metal ions, resulting in a decrease in the quantity of iron and its accumulation (Shoval et al. 2008).

Polyphenols' anti-inflammatory properties have been linked to a reduction in the risk of neurodegeneration. These chemicals can regulate the expression of pro-inflammatory genes such nitric oxide production, lipoxygenase, cyclooxygenase, chemokines, and numerous cytokines, mostly through NFkB and MAPK signaling. Curcumin has been found to suppress NFkB signaling, which results in chemokine and Aβ aggregate production being reduced (Korkina et al. 2011). Similarly, resveratrol can reduce A-mediated microglial inflammation (a hallmark of Alzheimer's disease) through a mechanism that involves the Toll-like receptor

4 (TLR4)/NF-kB/signal transducers and activators of transcription (STAT) signaling cascade, and EGCG can prevent amyloidogenesis by inhibiting neuroinflammatory cytokines released by astrocytes (Rahimifard et al. 2017).

Other processes can be attributed to polyphenol compounds' neuroprotective effects, one of which is the decrease in amyloid-beta (Aβ) aggregates and/or fibril development (a hallmark of AD). Curcumin, resveratrol, and EGCG have been shown to have a positive impact on direct disruption of β-pleated sheets in several in vitro experiments (Udhayakumar 2020). Polyphenols, in particular, appear to bind to diverse surface regions of the β-sheet structure, causing a variety of consequences, including the formation of short, nontoxic oligomers.

Polyphenols interact with various pathways engaged directly or indirectly in the neurodegenerative process, in addition to the processes mentioned above. They are particularly important in signaling pathways involved in survival, cell proliferation, apoptosis, and autophagy. Polyphenols impact cellular function in this way by changing the phosphorylation state and expression levels of proteins involved in the phosphoinositide 3-kinase (PI3K), Akt/protein kinase B (Akt/PKB), tyrosine kinases, and protein kinase C (PKC) signaling pathways. Protein kinase A (PKA), PKC, topoisomerase, mitochondrial ATPase, and the benzodiazepine binding sites of type A gamma-aminobutyric acid (GABA-A) receptors are all possible targets for flavonoids. Several protein kinases have also been found to be inhibited by resveratrol, and EGCG is shown to interfere with the PKC signaling pathway. Several studies have highlighted the importance of the PKC signaling route in regulating critical molecular processes involved in associative memory storage, as well as how a defect in the PKC signaling pathway plays a key role in the pathophysiology of NDs (Ajami et al. 2017).

The structure–activity connection of polyphenolic compounds is another important factor to consider when addressing their neuroprotective effects. The structure–activity connections linking the physiological actions of antioxidants, such as polyphenols, to their compositions and structures have received a lot of attention. Lu and colleagues investigated the structure–activity connection for various gallic acid derivatives' antioxidant activity in an in vitro liposome system, as well as their neuroprotective efficacy against 6-hydroxydopamine-induced stress in human neuroblastoma cells. The study found that polyphenolic chemicals' ability to scavenge free radicals and their hydrophobic characteristics, which allow them to easily penetrate cell membranes and reach their targets, are both critical for their neuroprotective impact against oxidative damage. More recently, an interesting research study used H_2O_2-scavenging activity and 1,1-diphenyl-2-picrylhydrazyl (DPPH)-scavenging activity tests to evaluate the antioxidant potential of certain polyphenolic compounds (Youdim and Mandel 2012). The findings revealed that the H_2O_2-scavenging activity of phenolic molecules is strongly influenced by the chemical structure of the molecule, as well as the type, number, and position of the active group (OH or NH_2) and the kind, number, and position of the substituted group. The combination of an amino group and an electron donor at the ortho or para position has a detrimental influence on the scavenging activity of polyphenolic compounds, according to the study. Similar to the number of active groups, the

DPPH-scavenging activity is proportional to the number of active groups; hence, more active compounds contain more than one active group (Ingale and Kasture 2014).

In vivo studies on numerous animal models have also revealed the neuroprotective benefits of curcumin, resveratrol, and EGCG. Mansouri et al. looked into the neuroprotective benefits of intraperitoneally administered curcumin against homocysteine-induced neuronal damage in a rat model of Parkinson's disease. The findings revealed that homocysteine had neurotoxic effects on dopaminergic neurons in the substantia nigra and curcumin therapy decreased apoptosis and alleviated behavior symptoms. In a *Drosophila melanogaster* model of HD, similar results were obtained (Ataie et al. 2010). Curcumin therapy dramatically reduces neuronal motor dysfunction by reducing cell death, according to researchers. Ishrat and colleagues established the efficiency of curcumin treatment in preventing cognitive deterioration in a rat model of sporadic dementia of the Alzheimer's type. The hippocampus and cerebral cortex of treated rats showed a substantial improvement in cognitive impairments, as well as a reduction in glutathione peroxidase (GPx), glutathione reductase (GR), and reduced glutathione (GSH) levels, and an increase in choline acetyltransferase (ChAT) activity. According to findings from a study done in a mouse model of HD, resveratrol therapy improved motor coordination and learning while also increasing the expression of mitochondrial-encoded electron transport chain genes. In a rat model of Alzheimer's disease, resveratrol has been shown to protect the brain against A-induced damage (Ishrat et al. 2009). Research on bioactive dietary polyphenol preparations found that resveratrol's neuroprotective benefits were linked to a decrease in inducible nitric oxide synthase (iNOS) levels and lipid peroxidation, as well as an increase in heme oxygenase-1 synthesis (HO-1). Karuppagounder and colleagues published similar findings, demonstrating that resveratrol can reduce plaque development in a brain-specific area in a mouse model of Alzheimer's disease. This positive impact on A was linked to a reduction in brain glutathione and a rise in cysteine, which is a precursor to glutathione.

Xu et al. have investigated the neuroprotective effects of EGCG in a mouse model of 1-methyl-4-phenyl-1,2,3,6-tetrahydropyridine (MPTP)-induced PD. By decreasing oxidative stress and modulating the iron-export protein ferroportin in the substantia nigra, EGCG alleviated MPTP-induced neurotoxicity. In a mouse model of Alzheimer's disease, the effects of EGCG on neuroinflammation and amyloidogenesis were investigated (Xu et al. 2020). The researchers discovered that EGCG therapy reduced memory impairment and neuronal cell apoptosis caused by lipopolysaccharide (LPS), as well as enhanced the production of tumor necrosis factor-alpha (TNF-1α), interleukin 1 beta (IL-1β), and interleukin 6 (IL-6). He and colleagues used an AD animal model to show that EGCG protects against neurodegeneration by lowering the levels of the amyloid precursor protein (APP) and Aβ in the hippocampus of afflicted mice. Overall, the data support the idea that dietary polyphenols, which primarily protect against Aβ plaque development, oxidative stress, and inflammation, can help postpone or prevent neurodegeneration (Rehman et al. 2021).

6.5 Advances in Application of Dietary Polyphenols to Treat Age-Related Neurological Disorders

6.5.1 Polyphenol Combination Therapy as a Novel Technique for Delaying the Onset of Alzheimer's Disease in People with Mild Cognitive Impairment

MCI is described as a syndrome characterized by subjective and/or objective evidence of cognitive impairment but no (or minimal) evidence of functional decline. Amnestic MCI (memory impairment) and nonamnestic MCI (nonmemory impairment) are two subtypes of MCI (affecting other cognitive domains only). Individuals with amnestic MCI are at a high risk of acquiring incident AD, and the majority of them have a high amyloid burden in their brains. Because people with MCI are by definition functioning well, finding therapies to prevent their development to dementia (secondary prevention of dementia) would be a significant public health benefit. There is presently no FDA-approved medication for secondary prevention of MCI, and trials of current Alzheimer's treatments have failed horribly. MCI is a risk group, not a disease state, and many people with MCI do not develop dementia or Alzheimer's disease; these people are unlikely to have a brain disease. Given these findings, it is especially critical that an intervention be reasonably safe and noninvasive (Lissek and Suchan 2021). The majority of existing interventions in this sector are cognitive or behavioral, with only a few medication trials, the most advanced of which being intranasal insulin, which is being investigated based on ideas that are similar to ours. MCI patients usually possess metabolic risk factors such as insulin resistance and prediabetes, putting them at an increased risk of cognitive deterioration (Biessels et al. 2014).

BDPP (bioactive dietary polyphenol preparation) is a novel nutraceutical combination that combines three bioactive and commercially available polyphenol products (Concord grape juice, grape seed extract, and resveratrol) to provide three selective, bioactive, polyphenol-rich dietary preparations to simultaneously target multiple AD pathogenic targets, as well as metabolic syndrome markers (primarily through resveratrol action). Each of the BDPP components has its own mode of action against AD pathogenic pathways, as we will go over in more detail below. As a result, when compared to individual BDPP components, BDPP application provides a more comprehensive coverage of AD pathogenic targets, making it a more effective method for treating individuals with early AD and prediabetes. They discovered that BDPP addresses amyloid burden, synaptic plasticity, and cognition in animal models of Alzheimer's disease and metabolic syndrome in current investigations. Those with prediabetes who have MCI are at a higher risk of developing Alzheimer's disease. This nutraceutical's benefits include a low risk of side effects, oral administration, and a refreshing lack of intellectual property difficulties, all of which help keep costs low. This is especially important as we move closer to a time when we may be able to target prodromal and preclinical Alzheimer's disease for secondary prevention. Because secondary prevention entails treating a large

population, it would be especially beneficial if a secondary preventive intervention was also economical, which is doubtful with the currently investigated treatments (for example, passive immunotherapy and beta-secretase inhibition) (Zhao et al. 2020).

6.5.2 *Polyphenols as Mitochondrial Medicine in Neurons*

Wine polyphenols have been shown to lower oxidative stress and boost the production of antioxidant enzymes such as catalase, superoxide dismutase, glutathione reductase, and glutathione peroxidase. Resveratrol increases antiapoptotic Bcl-2 protein expression while decreasing Bax protein expression. Resveratrol also acted as a mitochondrial antioxidant by increasing the levels of the antioxidants thioredoxin-2 (TRX2) and X-chromosome-linked inhibitor of apoptosis protein (Tsai et al. 2017). Another study discovered that resveratrol enhanced Bcl-2 expression, which prevented neuronal death. Resveratrol reduced mitochondria-mediated apoptosis and regulated oxidative stress in PC12 cells by downregulating Bax and upregulating Bcl-2. Similarly, lutein has been found to protect mice from ischemia damage by increasing Bcl-2 levels while decreasing Cox-2 and pancreatic ER kinase (PERK). Baicalein also inhibited mitochondrial apoptosis by reducing Bax and tBid expression and elevating Bcl-2-like proteins in the cytoplasm. Ferulic acid, a phenolic acid, inhibits mitochondrial apoptosis by inhibiting Bax and tBid expression and elevating Bcl-2-like proteins (Rodrigo et al. 2013). Flavones like chrysin, apigenin, and luteolin upregulate important ERK/Nrf2 pathway transcription factors including glutamate cysteine ligase catalytic (GCLC) and glutamate-cysteine ligase, modifier subunit (GCLM) to resist oxidative stress. The levels of glutathione peroxidase (GPx) were altered by red wine polyphenols, resulting in oxidative stress resistance. In hypoxia studies, the phenolic antioxidant 3,3′, 5,5′-tetra-t-butyl-biphenyl-4,4′-diol regulated both HIF-1α and GPx expression levels. Hesperidin carsonic acid, a key rosemary polyphenol, inhibits ROS, MAPKs, caspase-3, and COX-2 in neurons during hypoxic stress, resulting in significant anti-inflammatory effects. JNK inhibition is used as a mitochondrial treatment in not only stroke but also in Alzheimer's disease, as JNK activation contributes to tau hyperphosphorylation and A pathogenesis in the AD brain. Curcumin and resveratrol showed neuroprotection in astrocytes via increasing the activity of NAD(P)H quinone oxidoreductase (NQO1) via the Nrf2 pathway. Likewise, structurally modified isomers of resveratrol increased NQO1 activity, suggesting that antioxidant effects via the NRf2 pathway are possible. Endophilin-B1, otherwise known as SH3GLB1, which is essential for mitochondrial morphology and has a role in apoptosis, was regulated by ECG. Superoxide dismutase (SOD) and glutathione peroxidase (GPX1), two mitochondrial antioxidant enzymes, were also upregulated by EGCG (Bhullar and Rupasinghe 2013).

In a mouse model of hypoxic-ischemic (HI) brain damage, flavonoid-enriched fraction (AF4) isolates obtained from the peel of "Northern Spy" apples were shown

to suppress the expression of IL-1, TNF-, and IL-6. Phloridzin, another apple polyphenol, was shown to increase the expression of SOD1 and SOD2 genes, thus safeguarding mitochondria against oxidative stress. Polyphenols are essential mitochondrial therapies because they modulate apoptosis, antioxidant activity, signal transmission, and inflammation in mitochondrial biochemistry (Al-Gubory et al. 2010).

6.5.3 *Nanotechnology as a Novel Polyphenol Delivery Method*

The most well-studied nanoparticle-mediated polyphenol delivery techniques use biodegradable and biocompatible polymers to encapsulate polyphenolic compounds in nanostructures such as NSs, NCs, SLNs, CDs, LSs, and MCs. Oral, intravenous, intraperitoneal, and transdermal delivery are all options for delivering these nanoparticles. NSs are spherical particles with sizes ranging from 10 to 200 nm that have a hydrophobic component in the center and hydrophilic chains arranged on the surface. They protect the medication against enzymatic and chemical breakdown and might be amorphous or crystalline in form. Polyglycolic acid (PGA), polylactic acid (PLA), poly-lactic-co-glycolic acid (PLGA), polyethylene glycol (PEG), polycaprolactone (PCL), and chitosan (CS) are the most commonly used polymers for the preparation of nanoparticles because they have homogeneous solid matrices in which the polymer chains are organized in a frozen status phase-separated from the core of the solution. The medication is essentially dissolved, entrapped, encapsulated, or chemically attached to the polymer matrix (Siddiqui et al. 2009). Nanocapsules (NCs) have a diameter of 10–1000 nm. They are made up of a core–shell construction in which the medication is put in a cavity that is encased in a polymer membrane or coating. The medication can be in liquid, solid, or molecular dispersion form in the cavity of nanocapsules. In addition, active chemicals can be transported on nanovector surfaces or ingested through the polymeric membrane.

Solid lipid nanoparticles (SLNs) are nanoparticles that range in size from 50 to 1000 nanometers. They are one of the innovative possible colloidal carrier systems made up of lipid emulsions (oil in water) with a solid core lipid covered with aqueous surfactants in place of the liquid lipid. These nanoparticles have a number of benefits, including great biocompatibility, bioavailability, physical stability, and tolerability, as well as the capacity to preserve integrated labile medicines from degradation. Another benefit of using SLNs is the relative simplicity with which large-scale manufacturing may be accomplished. Nonetheless, particle development, an unpredictable gelation propensity, and unanticipated polymeric transition dynamics are all frequent drawbacks of these nanoparticles (Faridi Esfanjani and Jafari 2016).

Cyclodextrins (CDs) are a collection of structurally similar natural compounds that are formed when cellulose is digested by bacteria. CDs are toroidal or cone-shaped rather than perfect cylinders due to the limitation of unrestricted rotation around the bonds linking the glucopyranose units. The hydroxyl functions are directed to the cone's exterior, and the center cavity is covered with the glucose residues' skeletal carbons and ethereal oxygens. Alpha, beta, and gamma CDs are natural CDs that contain six, seven, and eight glucopyranose units, respectively. There have also been reports of CDs having 9 to 13 glucopyranose units. The CDs, particularly cyclodextrin, have a low water solubility. Many other types of modified CDs have been created, but only those made using water-soluble CD derivatives have been employed commercially in the pharmaceutical industry. The hydroxypropyl (HP), methyl (M), and sulfobutylether (SBE) substituents are present in these potent CD derivatives. CDs have been employed as complexing agents to boost the bioavailability and stability of weakly water-soluble medicines by incorporating them into the CD cavity via van der Waals forces, hydrophobic interactions, or hydrogen bonds (Nonaka et al. 2008).

The most well-studied nanosized carriers for targeted drug delivery are liposomes (LSs). LSs are phospholipid vesicles with particle sizes ranging from 30 nm to several micrometers that are made up of one or more concentric lipid bilayers surrounding aqueous gaps. They self-assemble by hydrating lipid powder in an aqueous solution including cholesterols, sphingolipids, glycolipids, membrane proteins, and nontoxic surfactants. Liposomal vesicles can encapsulate a wide spectrum of medicines due to their capacity to entrap both lipophilic and hydrophilic molecules; hydrophobic molecules are imprisoned in the lipid bilayer membrane, while hydrophilic molecules can be imbedded in the aqueous gaps. The ability to self-assemble and biocompatibility are two benefits of liposomal delivery methods. Furthermore, medication molecules are protected against early inactivation, degradation, and dilution in the circulation when they are encapsulated within liposomes (Squillaro et al. 2018).

Micelles (MCs) are self-assembled, nanoscale colloidal particles with diameters ranging from 5 to 100 nm. They are made up of amphiphilic copolymers that self-assemble in aquatic environments at specific concentrations and temperatures. When the surfactant concentration exceeds the critical micelle concentration (CMC), which is defined as "the minimum surfactant concentration necessary for the self-aggregation process," MCs develop. The hydrophilic parts of the surfactants pointing outward toward the solvent create the shells, while the hydrophobic pieces of the surfactants pointing toward the micelle's center or interior constitute the core (Ghaywat et al. 2021).

The use of biodegradable and biocompatible polymers allows for a more rational design of novel nanostructures capable of encapsulating polyphenols that can cross the BBB, overcoming the limits of traditional administration methods. Curcumin is the most researched therapeutic option in this situation, owing to promising results in animal models of neurodegenerative disorders. However, curcumin's efficiency has so far been restricted by its poor water solubility, low gastrointestinal adsorption, and fast metabolism. Crossing the BBB with poly-lactic-co-glycolic acid (PLGA)

nanospheres containing curcumin may be the best method. Curcumin–PLGA nanoparticles have been shown to interfere with A aggregation and enhance the brain self-repair process, boosting neural stem cell proliferation and neuronal differentiation in recent studies. Similarly, curcumin-loaded liposomes can effectively prevent the production of Aβ fibrils in vitro and their deposition in the brain. MD and central oxidative stress appear to be helped by curcumin–solid lipid nanoparticles. Curcumin and piperine co-loaded glycerol mono-oleate nanoparticles can also inhibit Syn aggregation, decreasing oxidative stress and apoptosis. Curcumin was also considered for administration to the central nervous system using nanoemulsions intranasally. Nanoemulsions of curcumin (added in the oil phase) may efficiently traverse the mucosa in the presence of CS without causing cytotoxicity (Rafiee et al. 2019).

Resveratrol is another potential possibility. It is well-known for its propensity to cause APP degradation and the removal of A. Resveratrol, on the other hand, has a variable bioavailability due to its fast and extensive metabolism. PEG-PCL and PLGA nanoparticles containing resveratrol provide a regulated release profile of the medication, which is necessary for maintaining its plasmatic level and antioxidant action. The oil-in-water nanoemulsion is a promising technique. With the addition of Vitamin E and other surfactants, this formulation can effectively reach the brain via the nasal route. Curcumin and resveratrol (1:1 weight ratio) are also co-encapsulated in mucoadhesive nanoemulsions, which shield the active ingredients from degradation and retain their antioxidant effects. In vivo quantification of the two polyphenols in the animal brain revealed an increase in their amounts after 6 hours. Unfortunately, these systems have not yet been tested in clinical trials, but the data gathered thus far encourages the development of novel treatment methods (Ratheesh et al. 2017).

6.6 Conclusion

Despite mounting evidence of dietary polyphenols' positive benefits in the prevention and treatment of NDs and brain tumors, their limited bioavailability is a major roadblock to their widespread use in clinical practice. Clinical hurdles researchers must overcome include a lack of clinical studies based on the use of polyphenols for the treatment of NDs and brain tumors, as well as a failure to replicate in vivo the therapeutic benefits seen in in vitro models. Neurodegenerative disorders are becoming a major issue for modern society as people live longer. In fact, as the population ages, neurodegenerative diseases will have a greater influence on medical and socioeconomic circumstances in industrialized countries. As a result, it is critical to developing techniques that help persons with dementia avoid cognitive deterioration and enhance their quality of life (Bhullar and Rupasinghe 2013).

Polyphenols are bioactive chemicals found in foods and drinks that have the ability to influence the metabolic process, therefore improving health and avoiding cognitive, motor, and sensory loss as people age. They also protect cells from stress

damage by modulating several cellular signaling pathways. Understanding the molecular processes by which polyphenols work is therefore critical for using them as dietary supplements to prevent neurodegenerative diseases. Polyphenols also protect mitochondria by activating prosurvival cell signaling, which protects them against pathogenic events. Polyphenols boost antioxidant enzymes including catalase and superoxide dismutase (SOD1, SOD2), as well as prosurvival pathways like Bcl-2 and PERK. The survival of neurons is also aided by the downregulation of Bad/Bax, c-jun, JNK, COX2, AP-1, and caspase-3.

Following advancements in the synthesis and characterization of novel materials, nanotechnologies have become widely employed in everyday life. Innovative nanotechnology-based technologies for improved drug delivery and cell targeting are expected to make significant advances in the medical and pharmacology areas.

Polyphenol research in the future should strive toward the clinical acceptability of health claims derived from preclinical in vitro and animal model studies. As a result, future research should focus on human clinical trials of various strong polyphenols and their combinations. Polyphenols must also be examined for risk assessment and safety evaluation in order to detect any negative effects. Polyphenols' pharmacological importance for humans will be determined by their clinical research results (Kumar 2015).

References

Ajami M, Pazoki-Toroudi H, Amani H et al (2017) Therapeutic role of sirtuins in neurodegenerative disease and their modulation by polyphenols. Neurosci Biobehav Rev 73:39–47. https://doi.org/10.1016/j.neubiorev.2016.11.022

Al-Gubory KH, Fowler PA, Garrel C (2010) The roles of cellular reactive oxygen species, oxidative stress and antioxidants in pregnancy outcomes. Int J Biochem Cell Biol 42:1634–1650. https://doi.org/10.1016/j.biocel.2010.06.001

Ataie A, Sabetkasaei M, Haghparast A et al (2010) Curcumin exerts neuroprotective effects against homocysteine intracerebroventricular injection-induced cognitive impairment and oxidative stress in rat brain. J Med Food 13:821–826. https://doi.org/10.1089/jmf.2009.1278

Bagetta D, Maruca A, Lupia A et al (2020) Mediterranean products as promising source of multi-target agents in the treatment of metabolic syndrome. Eur J Med Chem 186:111903. https://doi.org/10.1016/j.ejmech.2019.111903

Bhullar KS, Rupasinghe HPV (2013) Polyphenols: multipotent therapeutic agents in neurodegenerative diseases. Oxidative Med Cell Longev 2013:891748. https://doi.org/10.1155/2013/891748

Biessels GJ, Strachan MWJ, Visseren FLJ et al (2014) Dementia and cognitive decline in type 2 diabetes and prediabetic stages: towards targeted interventions. Lancet Diabetes Endocrinol 2:246–255. https://doi.org/10.1016/S2213-8587(13)70088-3

Dai J, Mumper RJ (2010) Plant phenolics: extraction, analysis and their antioxidant and anticancer properties. Molecules 15:7313–7352. https://doi.org/10.3390/molecules15107313

Darvesh AS, Carroll RT, Bishayee A et al (2010) Oxidative stress and Alzheimer's disease: dietary polyphenols as potential therapeutic agents. Expert Rev Neurother 10:729–745. https://doi.org/10.1586/ern.10.42

Darvesh AS, McClure M, Sadana P et al (2017) Neuroprotective properties of dietary polyphenols in Parkinson's disease. In: Farooqui T, Farooqui AA (eds) Neuroprotective effects of phytochemicals in neurological disorders. John Wiley & Sons, Inc., Hoboken, NJ, pp 243–263

Das S, Das DK (2007) Anti-inflammatory responses of resveratrol. Inflamm Allergy Drug Targets 6:168–173. https://doi.org/10.2174/187152807781696464

Faridi Esfanjani A, Jafari SM (2016) Biopolymer nano-particles and natural nano-carriers for nano-encapsulation of phenolic compounds. Colloids Surf B Biointerfaces 146:532–543. https://doi.org/10.1016/j.colsurfb.2016.06.053

Farzaei MH, El-Senduny FF, Momtaz S et al (2018) An update on dietary consideration in inflammatory bowel disease: anthocyanins and more. Expert Rev Gastroenterol Hepatol 12:1007–1024. https://doi.org/10.1080/17474124.2018.1513322

Francis FJ (1982) Analysis of anthocyanins. In: Anthocyanins as food colors. Elsevier, pp 181–207

Ghaywat SD, Mate PS, Parsutkar YM et al (2021) Overview of nanogel and its applications. GSC Biol Pharm Sci 16:040–061. https://doi.org/10.30574/gscbps.2021.16.1.0196

Ghosh R, Tabrizi SJ (2018) Clinical features of Huntington's disease. Adv Exp Med Biol 1049:1–28. https://doi.org/10.1007/978-3-319-71779-1_1

Gottlieb M, Leal-Campanario R, Campos-Esparza MR et al (2006) Neuroprotection by two polyphenols following excitotoxicity and experimental ischemia. Neurobiol Dis 23:374–386. https://doi.org/10.1016/j.nbd.2006.03.017

Halliday GM, McCann H (2010) The progression of pathology in Parkinson's disease. Ann N Y Acad Sci 1184:188–195. https://doi.org/10.1111/j.1749-6632.2009.05118.x

Han X, Shen T, Lou H (2007) Dietary polyphenols and their biological significance. IJMS 8:950–988. https://doi.org/10.3390/i8090950

Hano C, Tungmunnithum D (2020) Plant polyphenols, more than just simple natural antioxidants: oxidative stress, aging and age-related diseases. Medicines (Basel) 7:26. https://doi.org/10.3390/medicines7050026

Holley SM, Kamdjou T, Reidling JC et al (2018) Therapeutic effects of stem cells in rodent models of Huntington's disease: review and electrophysiological findings. CNS Neurosci Ther 24:329–342. https://doi.org/10.1111/cns.12839

Inanami O, Asanuma T, Inukai N et al (1995) The suppression of age-related accumulation of lipid peroxides in rat brain by administration of rooibos tea (*Aspalathus linearis*). Neurosci Lett 196:85–88. https://doi.org/10.1016/0304-3940(95)11853-o

Ingale SP, Kasture SB (2014) Antioxidant and antiparkinsonian activity of Passiflora incarnata leaves. Orient Pharm Exp Med 14:231–236. https://doi.org/10.1007/s13596-014-0149-3

Ishrat T, Parveen K, Khan MM et al (2009) Selenium prevents cognitive decline and oxidative damage in rat model of streptozotocin-induced experimental dementia of Alzheimer's type. Brain Res 1281:117–127. https://doi.org/10.1016/j.brainres.2009.04.010

Kamat CD, Gadal S, Mhatre M et al (2008) Antioxidants in central nervous system diseases: preclinical promise and translational challenges. J Alzheimers Dis 15:473–493

Kang GG, Francis N, Hill R et al (2019) Dietary polyphenols and gene expression in molecular pathways associated with type 2 diabetes mellitus: a review. Int J Mol Sci 21(1):140. https://doi.org/10.3390/ijms21010140

Kelsey NA, Wilkins HM, Linseman DA (2010) Nutraceutical antioxidants as novel neuroprotective agents. Molecules 15:7792–7814. https://doi.org/10.3390/molecules15117792

Klatt P, Lamas S (2000) Regulation of protein function by S-glutathiolation in response to oxidative and nitrosative stress. Eur J Biochem 267:4928–4944. https://doi.org/10.1046/j.1432-1327.2000.01601.x

Korkina L, Kostyuk V, De Luca C, Pastore S (2011) Plant phenylpropanoids as emerging anti-inflammatory agents. Mini Rev Med Chem 11:823–835

Kumar R (2015) Development and elucidation of mechanism of action of new leads to attenuate NEUROINFLAMMATION in stroke model. Undergraduate thesis

Lassmann H (2018) Multiple sclerosis pathology. Cold Spring Harb Perspect Med 8(3):a028936. https://doi.org/10.1101/cshperspect.a028936

Lassmann H, van Horssen J, Mahad D (2012) Progressive multiple sclerosis: pathology and pathogenesis. Nat Rev Neurol 8:647–656. https://doi.org/10.1038/nrneurol.2012.168

Lissek V, Suchan B (2021) Preventing dementia? Interventional approaches in mild cognitive impairment. Neurosci Biobehav Rev 122:143–164. https://doi.org/10.1016/j.neubiorev.2020.12.022

Matkowski A, Kus P, Goralska E, Wozniak D (2013) Mangiferin–a bioactive xanthonoid, not only from mango and not just antioxidant. Mini Rev Med Chem 13:439–455

McKay DL, Blumberg JB (2007) A review of the bioactivity of south African herbal teas: rooibos (*Aspalathus linearis*) and honeybush (*Cyclopia intermedia*). Phytother Res 21:1–16. https://doi.org/10.1002/ptr.1992

Milatovic D, Gupta RC, Zaja-Milatovic S, Aschner M (2009) Excitotoxicity, oxidative stress, and neuronal injury. In: Handbook of toxicology of chemical warfare agents. Elsevier, pp 633–651

Nonaka N, Farr SA, Kageyama H et al (2008) Delivery of galanin-like peptide to the brain: targeting with intranasal delivery and cyclodextrins. J Pharmacol Exp Ther 325:513–519. https://doi.org/10.1124/jpet.107.132381

Oliviero F, Scanu A, Zamudio-Cuevas Y et al (2018) Anti-inflammatory effects of polyphenols in arthritis. J Sci Food Agric 98:1653–1659. https://doi.org/10.1002/jsfa.8664

Przedborski S, Vila M, Jackson-Lewis V (2003) Series introduction: neurodegeneration: what is it and where are we? J Clin Invest 111:3–10. https://doi.org/10.1172/JCI200317522

Rafiee Z, Nejatian M, Daeihamed M, Jafari SM (2019) Application of different nanocarriers for encapsulation of curcumin. Crit Rev Food Sci Nutr 59:3468–3497. https://doi.org/10.1080/10408398.2018.1495174

Rahimifard M, Maqbool F, Moeini-Nodeh S et al (2017) Targeting the TLR4 signaling pathway by polyphenols: a novel therapeutic strategy for neuroinflammation. Ageing Res Rev 36:11–19. https://doi.org/10.1016/j.arr.2017.02.004

Ratheesh G, Tian L, Venugopal JR et al (2017) Role of medicinal plants in neurodegenerative diseases. Biomanuf Rev 2:2. https://doi.org/10.1007/s40898-017-0004-7

Rehman IU, Ahmad R, Khan I et al (2021) Nicotinamide ameliorates amyloid beta-induced oxidative stress-mediated neuroinflammation and neurodegeneration in adult mouse brain. Biomedicines 9(4):408. https://doi.org/10.3390/biomedicines9040408

Rodrigo R, Fernández-Gajardo R, Gutiérrez R et al (2013) Oxidative stress and pathophysiology of ischemic stroke: novel therapeutic opportunities. CNS Neurol Disord Drug Targets 12:698–714. https://doi.org/10.2174/18715273113120500015

Scalbert A, Johnson IT, Saltmarsh M (2005) Polyphenols: antioxidants and beyond. Am J Clin Nutr 81:215S–217S. https://doi.org/10.1093/ajcn/81.1.215S

Selkoe DJ (1991) The molecular pathology of Alzheimer's disease. Neuron 6:487–498. https://doi.org/10.1016/0896-6273(91)90052-2

Sharma RA, Gescher AJ, Steward WP (2005) Curcumin: the story so far. Eur J Cancer 41:1955–1968. https://doi.org/10.1016/j.ejca.2005.05.009

Shoval H, Weiner L, Gazit E et al (2008) Polyphenol-induced dissociation of various amyloid fibrils results in a methionine-independent formation of ROS. Biochim Biophys Acta 1784:1570–1577. https://doi.org/10.1016/j.bbapap.2008.08.007

Siddiqui IA, Adhami VM, Bharali DJ et al (2009) Introducing nanochemoprevention as a novel approach for cancer control: proof of principle with green tea polyphenol epigallocatechin-3-gallate. Cancer Res 69:1712–1716. https://doi.org/10.1158/0008-5472.CAN-08-3978

Snijman PW, Joubert E, Ferreira D et al (2009) Antioxidant activity of the dihydrochalcones Aspalathin and Nothofagin and their corresponding flavones in relation to other rooibos (*Aspalathus linearis*) flavonoids, epigallocatechin Gallate, and Trolox. J Agric Food Chem 57:6678–6684. https://doi.org/10.1021/jf901417k

Squillaro T, Cimini A, Peluso G et al (2018) Nano-delivery systems for encapsulation of dietary polyphenols: an experimental approach for neurodegenerative diseases and brain tumors. Biochem Pharmacol 154:303–317. https://doi.org/10.1016/j.bcp.2018.05.016

Stadelmann C (2011) Multiple sclerosis as a neurodegenerative disease: pathology, mechanisms and therapeutic implications. Curr Opin Neurol 24:224–229. https://doi.org/10.1097/WCO.0b013e328346056f

Street RA, Prinsloo G (2013) Commercially important medicinal plants of South Africa: a review. J Chem 2013:1–16. https://doi.org/10.1155/2013/205048

Stutzmann GE (2007) The pathogenesis of Alzheimers disease is it a lifelong "calciumopathy"? Neuroscientist 13:546–559. https://doi.org/10.1177/1073858407299730

Taylor AE, Saintcyr JA (1995) The neuropsychology of Parkinsons-disease. Brain Cogn 28:281–296. https://doi.org/10.1006/brcg.1995.1258

Tian B, Liu J (2020) Resveratrol: a review of plant sources, synthesis, stability, modification and food application. J Sci Food Agric 100:1392–1404. https://doi.org/10.1002/jsfa.10152

Tønnesen HH, Karlsen J (1985) Studies on curcumin and curcuminoids. VI. Kinetics of curcumin degradation in aqueous solution. Z Lebensm Unters Forsch 180:402–404. https://doi.org/10.1007/BF01027775

Tsai H-Y, Ho C-T, Chen Y-K (2017) Biological actions and molecular effects of resveratrol, pterostilbene, and 3′-hydroxypterostilbene. J Food Drug Anal 25:134–147. https://doi.org/10.1016/j.jfda.2016.07.004

Tsuji S (2002) Contribution of Japanese researchers to progress in the field of neurology in the last 100 years: Dentatorubral-pallidoluysian atrophy. Nippon Naika Gakkai Zasshi 91:2296–2301

Tuñón MJ, García-Mediavilla MV, Sánchez-Campos S, González-Gallego J (2009) Potential of flavonoids as anti-inflammatory agents: modulation of pro-inflammatory gene expression and signal transduction pathways. Curr Drug Metab 10:256–271. https://doi.org/10.2174/138920009787846369

Udhayakumar B (2020) Myloid beta (Aβ) aggregates and/or fibril development... - Google Scholar. Brain Amyloidopathy in a Mouse Model of Alzheimer's Pathology

Valls V, Peiro C, Muñiz P, Saez GT (2005) Age-related changes in antioxidant status and oxidative damage to lipids and dna in mitochondria of rat liver. Process Biochem 40:903–908. https://doi.org/10.1016/j.procbio.2004.02.025

van der Burg JMM, Björkqvist M, Brundin P (2009) Beyond the brain: widespread pathology in Huntington's disease. Lancet Neurol 8:765–774. https://doi.org/10.1016/S1474-4422(09)70178-4

Vonsattel JP, DiFiglia M (1998) Huntington disease. J Neuropathol Exp Neurol 57:369–384. https://doi.org/10.1097/00005072-199805000-00001

Williams RJ, Spencer JPE, Rice-Evans C (2004) Flavonoids: antioxidants or signalling molecules? Free Radic Biol Med 36:838–849. https://doi.org/10.1016/j.freeradbiomed.2004.01.001

Xing L, Zhang H, Qi R et al (2019) Recent advances in the understanding of the health benefits and molecular mechanisms associated with green tea polyphenols. J Agric Food Chem 67:1029–1043. https://doi.org/10.1021/acs.jafc.8b06146

Xu Q, Chen Z, Zhu B et al (2020) A-type cinnamon Procyanidin oligomers protect against 1-Methyl-4-Phenyl-1,2,3,6-Tetrahydropyridine-induced neurotoxicity in mice through inhibiting the P38 mitogen-activated protein kinase/P53/BCL-2 associated X protein signaling pathway. J Nutr 150:1731–1737. https://doi.org/10.1093/jn/nxaa128

Youdim BH, Mandel S (2012) Orly Weinreb, Tamar Amit, Moussa. In: Flavonoids and related compounds: bioavailability and function

Zhao D, Simon JE, Wu Q (2020) A critical review on grape polyphenols for neuroprotection: strategies to enhance bioefficacy. Crit Rev Food Sci Nutr 60:597–625. https://doi.org/10.1080/10408398.2018.1546668

Preetham Elumalai
Sreeja Lakshmi *Editors*

Lectins

Innate Immune Defense and Therapeutics

Springer

Lectins

Preetham Elumalai • Sreeja Lakshmi
Editors

Lectins

Innate Immune Defense and Therapeutics

Springer

Editors
Dr. Preetham Elumalai
Department of Marine Biology, Microbiology and Biochemistry, School of Marine Sciences
Cochin University of Science and Technology
Cochin, Kerala, India

Dr. Sreeja Lakshmi
School of Ocean Science and Technology
Kerala University of Fisheries and Ocean Studies
Cochin, Kerala, India

ISBN 978-981-16-7461-7 ISBN 978-981-16-7462-4 (eBook)
https://doi.org/10.1007/978-981-16-7462-4

© The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature Singapore Pte Ltd. 2021
This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors, and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Preface

Lectins: Innate Immune Defense and Therapeutics focuses on exploring the importance of lectins in immune defense and modern therapeutic approaches. Lectins are protein molecules, widely distributed in different species in almost all organisms including plants, animals, viruses, bacteria, cyanobacteria and yeasts. They serve as receptors for recognizing carbohydrate moieties present on the pathogenic surfaces and exert a specific interaction with them. Following the discovery of animal lectins, research in basic and applied biosciences experienced an accelerated thrust because of its role in mediating cell-cell interactions, host cell-pathogen interactions, antimicrobial activity, drug discovery, etc. Our book is anticipated to provide an overview on different types of lectins and future perspectives in scientific research as recognition and effector molecules in innate immunity or regulators of adaptive immune responses. We really appreciate the contributions of the authors for their expertise and skilful renditions. The facts about Lectins presented in this book will provide an overview to newcomers and a meticulous illustration to the specialists in the field.

Cochin, Kerala, India

Preetham Elumalai
Sreeja Lakshmi

Contents

1 **Overview of Lectins** 1
M. S. Prachi Vibhute, Mohamed Jaabir, S. Sangeetha Bharath, and Jeyachandran Sivakamavalli

2 **Structure, Biosynthesis, and Biological Properties of Lectins** 27
N. S. Kaviyarasi

3 **Classification of Lectins** 51
Akshaya Radhakrishnan, Kiyun Park, Ihn-Sil Kwak, Mohamed Jaabir, and Jeyachandran Sivakamavalli

4 **Molecular Basis of Lectin–Carbohydrate Interaction** 73
Yashika Pusam, Mohamed Jaabir, and Sivakamavalli Jeyachandran

5 **Animal Lectin** 89
Sahya Narayanan, Akhila Raj Pallan, Akshay Balakrishnan, Eldho J. Paul, and Preetham Elumalai

6 **Plant Lectins** 107
Abdullah Bin Abdul Nazar, Aneetta Skinner, Debarghya Ghosh Dastidar, and Preetham Elumalai

7 **Microbial Lectins** 131
Abdul Salam Rubeena, Abigith Abraham, and K. M. Aarif

8 **Regulation of Immune Responses by Lectins** 147
Shamna Naseemashahul and Femi John Fawole

9 **Lectin–Carbohydrate Interactions in Pathogenesis** 165
Anbazhagan Veerappan and Siva Bala Subramaniyan

10 Lectins in Health and Diseases: Mannan-Binding Lectin and Infectious Diseases 185
Sadhana Sharma, Pankaj Kumar Patel, Komal Choudhary, Parija P. Phadnavis, Sonali R Bhagwat, Sumati Hajela, Abhilasha, Rajesh Kumar Gupta, and Krishnan Hajela

11 Lectins in Health and Diseases: Galectins and Cancer 215
Shirsha Nandi, Sayantani Ghosh, Amit Ranjan, Rajkumar S. Sood, Jayanta K. Pal, Krishnan Hajela, and Rajesh Kumar Gupta

12 Lectins in Diagnostic Tools and Therapeutic Agents 273
Mani Divya, Sekar Vijayakumar, and Baskaralingam Vaseeharan

13 Modern Approach in Lectin-Based Nanomedicine 285
Arivarasan Vishnu Kirthi, Loganathan Karthik, and Babu Gajendran

Chapter 4
Molecular Basis of Lectin–Carbohydrate Interaction



Yashika Pusam, Mohamed Jaabir, and Sivakamavalli Jeyachandran

Abstract The ability to bind with carbohydrate molecules has been considered as a significant characteristic of lectins, and lot of such investigations have been conducted from the past two decades. That information shows that it has unique interaction with the small molecules which are predominantly hydrophobic in nature. Also the recent reports show that surface lectins are easier to be expressed with many cells, which as a result are used as recognition molecules, by interacting with the carbohydrates that are present in the opposing cells. The lectins that are extracted from the various sources like plants, animals, and bacteria are responsible for the interaction of sugar onto the respective cell surface. In medicine, there is a lot of room for mediation of animal receptors and bacterial toxic proteins (toxins) mediated through various mechanisms such as pathogen neutralization, glycol-conjugate absorption, cell to cell contacts, and pathogen neutralization. Plant poisons and mitogens are some of the examples that are formed due to lectin–carbohydrate interaction. A recent example of this interaction between lectin and carbohydrate is during the blood clotting and inflammation, the cell adhesion molecules mediate the adhesion of leukocytes to carbohydrates that are present on the endothelium. The structural features of subsite and subunit multi-valency confer context-specific functional properties in some lectin types which are usually seen as X-ray crystal structures. Hence in this chapter we are discussing the interaction between lectin and carbohydrate along with an elaborated explanation of its physical and functional properties and its application in various fields such as drug delivery system, cancer biology, hydrogen bonding, metal coordination bonds, and so on.

Keywords Carbohydrate · Lectin · Molecular interaction · Galactose/*N*-acetylgalactosamine · Agglutinin

Y. Pusam · M. Jaabir · S. Jeyachandran (✉)
PG Research and Department of Biotechnology and Microbiology, National College (Autonomous), Tiruchirappalli, Tamil Nadu, India

© The Author(s), under exclusive license to Springer Nature Singapore Pte Ltd. 2021

P. Elumalai, S. Lakshmi (eds.), *Lectins*,
https://doi.org/10.1007/978-981-16-7462-4_4

Abbreviation

Arg	Arginine
ASGPR	Asialoglycoprotein receptor
Asn	Asparagine
CDRs	Carbohydrate recognition domain
Con A	Concanavalin A
ECorL	*Erythrina corallodendron lectin*
Fuc	Fucose
Gal	Galactose/*N*-acetylgalactosamine
GalNAc	*N*-acetylneuraminic acid
GlcNAc	*N*-acetylglucosamine
Glu	Glutamic acid
His	Histidine
LBL	Lima bean lectin
Man	Mannose
PHA	*Phytohaemagglutinin*
PNA	Peanut agglutinin
SBA	*Soybean agglutinin*
Tant	T-antigenic
UEA	*Ulex europaeus*

4.1 Introduction

Lectins are basically proteins or non-immune proteins which usually bind with sugar molecules based on several factors such as binding sites (at least two), agglutination of animal or plant cells, precipitated polysaccharides, glycolipids, and even glycoproteins (Kennedy et al. 1995). As far the information and data from the past decade show that lectins have the ability to bind with carbohydrates in a unique manner along with some biological process of cells and proteins. In order to determine the specific protein and carbohydrate groups, X-ray crystallography technique is used by understanding the morphological structure in a crystalline form, and also it is used to study bond formation. The first ever lectin to be crystallized is Concanavalin A (Con A) and this crystallized lectin shows a lesser agglutination activity with the sugar groups, especially with sucrose (Liener 1976).

The denaturation of protein is estimated by ΔCP and ΔH values based on the protein–protein interaction, binding of oligopeptide-protein, surface area of participating molecules with water accessibility (both polar and apolar) (Chervenak and Toone 1995). Lectins are capable of regulating diverse varieties of biological processes via interaction with carbohydrates in specific manner (Sharon and Lis 1989) The structural studies of lectins unveil the recognition between the carbohydrates and lectins. By the quantitative understanding of the molecular basis with the

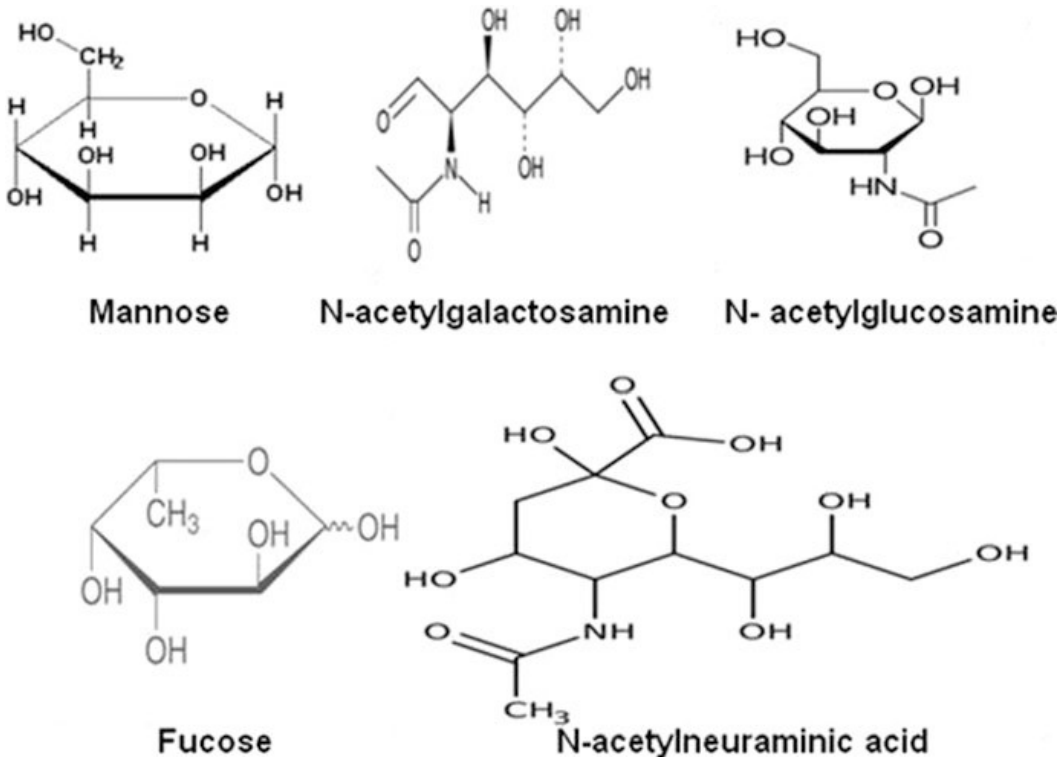


Fig. 4.1 Structures of monosaccharide ligand

affinity of the binding systems of lectins, it is possible to use it in the drug delivery system (Toone 1994). Many vital biological processes depend on recognition of these binding sites which include clearance of glycoprotein from system, control glycoprotein, immune system, as well as cancer biology. Detailed study of molecular level binding of lectin–carbohydrate interaction can lead to drug designing for treating a wide range of diseases which also include cancer inflammation (Loris 2002). Based on the bond formation abilities the interaction between lectin and carbohydrate is done, the bond formation ability is specific to that of Van der Waals interaction, hydrogen bonds, hydrophobic interaction, and even metal coordination bond. For example, the cross-linking and precipitation of blood cells lead to surface sugar interaction of erythrocytes, so from these phenomena it is understood that the lectin has multiple binding sites, which is basically called as cell agglutination (Sharon and Lis 1972). Cell agglutination is found in various wide range organisms such as invertebrates, vertebrates, bacteria, fungi, and viruses. Based on the structural binding of the receptor and its ligand, the lectin has sugar specificity and also the carbohydrates and lectin interaction is a highly specific reversible reaction. According to Sharon et al. the lectins are classified into 5 groups based on high affinity to the monosaccharide ligands. They are mannose, galactose/*N*-acetylgalactosamine, *N*-acetylglucosamine, fucose, *N*-acetylneuraminic acid, *N*-acetyl galactose-4-sulfate and mannose-6-phosphate (Ambrosi et al. 2005) (Fig. 4.1).

4.2 Types of Lectin and Its Interaction with Other Molecules

4.2.1 Plant Lectins

4.2.1.1 Legume Lectin

Legumes lectins are specifically family of proteins that bind with the sugar groups and these are the most studied class of protein family over more than 100 of other family members, these legume lectins are isolated from the cortical region of seeds, roots, and bark regions of the family *Fabaceae* (Sharon and Lis 1990). The main function of these naturally occurring lectins is that they are released against the predators as a defensive mechanism. *Concanavalin* A, *phytohaemagglutinin* (PHA), *soybean agglutinin* (SBA), *peanut agglutinin* (PNA), and coral tree or *Erythrina corallodendron lectin* (ECorL) are some of the examples of legume lectins (Sumner and Howell 1936). So this helps in understanding the whole mechanism behind the lectin–carbohydrate interaction, because it is easily purifiable and has higher sugar specificity (Sharon and Lis 1990). The legume lectin has the ability to interact with many quaternary structures; because of this these lectins are used as model systems for understanding the protein–carbohydrate interaction (Rojo et al. 2002). Legume lectin has the ability to differentiate between various carbohydrates that are similar, like galactose and glucose are closely related. This phenomenon is possible by the slight change or configuration of a single hydroxyl group (4-OH) (Bourne et al. 1994). They consist of 2–4 subunits that are slightly heterogeneous in nature and with a similarity of 25–30 kDa. For binding an atom is present strongly attached to calcium and manganese ions. Ca^{++} and Mg++ are located very close to carbohydrate binding sites. Many amino acids play an important role in the interaction by forming hydrogen bond with monosaccharide at the binding site. In case of legume lectins four amino acids plays major role, i.e. glycine, leucine, aspartic acid, asparagines. Sometimes amino acid can differ within the species like in PNAleucine is replaced by tyrosine (Sharon and Lis 2001) (Table 4.1).

Hydrogen bond and hydrophobic interaction causes binding of lectin to carbohydrates, which is represented by T-antigenic disaccharide in PNA, which shows Galβ(1→3) -GalNAc (Tant) binding. Overall interaction is done by Van der Waals

Table 4.1 Example of Legume lectin with ligand

Legume lectins	Ligand	Reference
Concanavalin A (Jack bean)	Man/Glc	Gupta et al. (1996)
Phaseolus vulgaris (French bean)	–	Ye et al. (2001)
Peanut agglutinin (Peanut)	Gal, Galβ3GalNAcα	Ambrosi et al. (2005)
Soybean agglutinin (Soybean)	Gal/GalNAc	Rao et al. (1998)
Pisum sativum (Pea)	Man/Glc	Davey and Dudman (1979)
Lens culinaris (Lentil)	Man/Glc	Pavelka and Ellinger (1989)
Dolichos biflorus (Horse gram)	GalNAcα3GalNAc, GalNAc	Ambrosi et al. (2005)

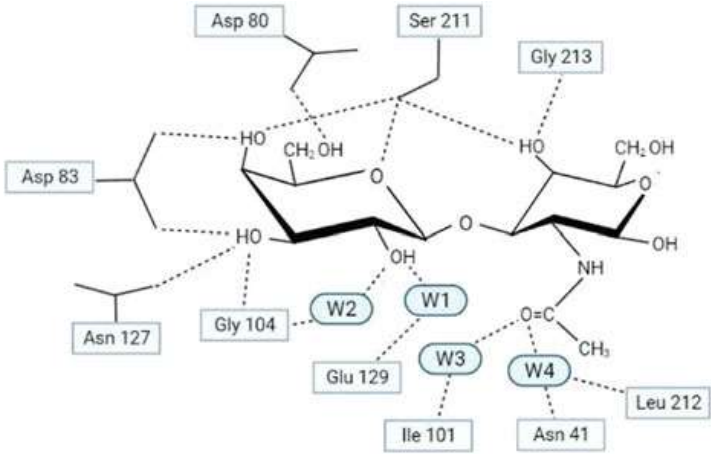


Fig. 4.2 Protein–carbohydrate interaction PAN-Tant complex (created with biorender.com)

force. Hydrophobic patches on the galactosyl surface are created by the steric effect of the hydroxyl group of carbohydrates, which can interact with protein hydrophobic regions (Van Den Hamer et al. 1970). A water molecule plays an important role in ligand–protein contact as well as (Quiocho 1989) recognition of carbohydrates. Apart from T-antigen (Tant), some other ligand of PNA is present like methyl-*b*-galactoside (MeGal), *N*-acetyllactosamine, (LacNAc44), and lactose (Lac) which are connected with water bridges and have four water complexes W1, W2, W3, and W4 (Davey and Dudman 1979) (Fig. 4.2).

4.2.1.2 Ricin Lectin

Ricin is a cytotoxic glycoprotein discovered in the seeds of the castor plant that is heterodimeric (AB), also known as R-type lectin. Carbohydrate-binding sites (specific for galactose and *N*-acetylgalactosamine) are present in the heavy B-chain (Rutenber and Robertus 1991). The B-chain can attach to cell surface glycolipids and glycoproteins with beta-1,4-linked galactose residues, allowing the poisonous protein (ricin's A-chain) to enter the cell more easily. The A-chain functions as an enzyme (Rutenber et al. 1991). It has the ability to catalytically disrupt protein synthesis and is extremely hazardous that a single molecule is all that is required to destroy a cell (Endo and Tsurugi 1987).

The R-type lectin family is represented in both mammals and plants (Ricin-B family in plants). In mammals, fibroblast growth factors and the cysteine-rich domain of the mannose receptor have structurally similar domains (Pohleven et al. 2009). Although both ricin and the mannose receptor can bind galactose-containing glycan complexes, their carbohydrate binding sites are significantly different. Lactose binding is only seen at two of the six possible sites in the ricin–lactose complex's X-ray crystal structure. Galactose C3 and C4 hydroxyl groups donate hydrogen bonds to an aspartic acid residue's side-chain carboxyl oxygen atoms at both positions, galactose C3 and C4 hydroxyl groups donate hydrogen bonds to an

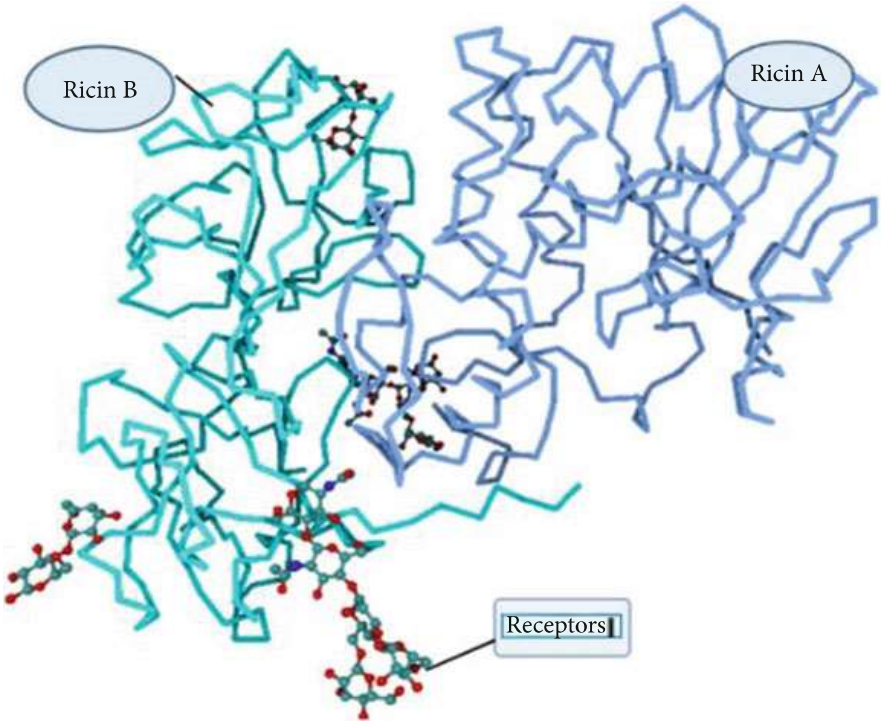


Fig. 4.3 Ricin–lactose complex with heterodimeric chain and mannose receptors (Created with biorender.com)

aspartic acid residue's side-chain carboxyl oxygen atoms at both positions (Lord et al. 2003) (Fig. 4.3).

4.2.2 Animal Lectin

Various types of animal lectin present which can be classified into the basis of their solubility or specificity, i.e. S-lectin and C-lectin are among the animal lectins which are studied first.

4.2.2.1 S-Lectins

Maximum of S-lectin is β-galactose specific and soluble in nature whereas C-lectin is ion dependent like Ca^{++}. S-lectin has protein subunit of 14–35 kD. As per the studies S-lectin in tissue organization, cell adhesion, differentiation, and morphogenesis is possible due to the binding of poly-*N*-acetyllactosamine with protein laminin membrane. S-lectin is commonly called as galectin they share primary structural homology with carbohydrate recognition domain (CDRs). The branching pattern or structure of galectin is Galβ1–3/4GlcNaC which is very specific (Barondes et al. 1994a).

The binding affinity of S-lectin is very low, in the millimolar range. Although all galectins appear to bind terminal β-galactosides, their identification of galactosyl residues within oligosaccharides varies significantly. The C4 and C6 hydroxyls of galactose, as well as the C3 hydroxyl of GlcNAc, were found to be tightly recognized when galectins were co-crystallized with simple galactoside-containing disaccharides. Galectin-1 has been found to have a substantially higher affinity for bigger glycans with repeated galactosyl residues, such as those seen in type-2 polylactosamine sequences represented by the structure -3Galβ1–4GlcNAcβ1–3-Galβ1–4GlcNAcβ1–3Galβ1–4GlcNAcβ1-R (Kilpatrick 2002). Each galectin has somewhat different oligosaccharide binding selectivity and macromolecular ligand affinity. Because galectin-1 only binds to a small number of glycoconjugates, it appears that the presence of galactose residues in glycoconjugates is insufficient to induce high-affinity binding to this lectin. These lectins have been proposed to have both intracellular and extracellular functions, including a role in modulating cell–cell and cell–matrix interactions. The C4 hydroxyl group of galactose is hydrogen bonded to His45, Asn47, and Arg49 in the carbohydrate-binding site, residues that are completely conserved across all galectin sequences (Sharon and Lis 2013).

4.2.2.2 C-Lectin

This lectin belongs to the collectin family, which is a group of soluble lectins that belong to the Ca^{2+}-dependent C-type lectin superfamily (Weis et al. 1998). Each of these proteins has one or more carbohydrate-recognition domains (CRDs), as well as domains that are responsible for the molecule's other functions. Ca++ is required for carbohydrate binding by all C-type lectins, though they have different specificities. The function of the metal ions (Ca^{++} and Mn^{++}) in the legume lectins, as explained earlier, differs fundamentally from the function of the Ca^{++} as a direct sugar ligand in the mannose-binding protein A. The carboxy-terminal amino acid residues that ligate both the Ca^{++} and the mannose are found there (Drickamer and Fadden 2002). The mannose 3-OH is hydrogen bound to one carbonyl of Glu185 and an amide of Asn187, whereas the 4-OH is hydrogen bonded to a carbonyl of Glu193 and an amide of Asn205. Both hydroxyls bind directly with Ca^{++}, which is then coordinated with four carbonyl groups, one from each of the amino acids' side chains. The wide diversity of carbohydrate structures recognized by this lectin, as well as the strong binding of multivalent ligands, could be explained by the presence of numerous binding sites with different affinities for oligosaccharides (Kolatkar and Weis 1996). The binding selectivity of C-type lectins is diverse. Although the relative affinities for sugars in this group vary, several of these lectins bind derivatives of Man and GlcNAc (Man-type ligands) (Fig. 4.4). They form a network of hydrogen bonds with the side chains of amino acids, which also serve as equatorial ligands for this divalent cation (Chervenak and Toone 1995) (Fig. 4.5).

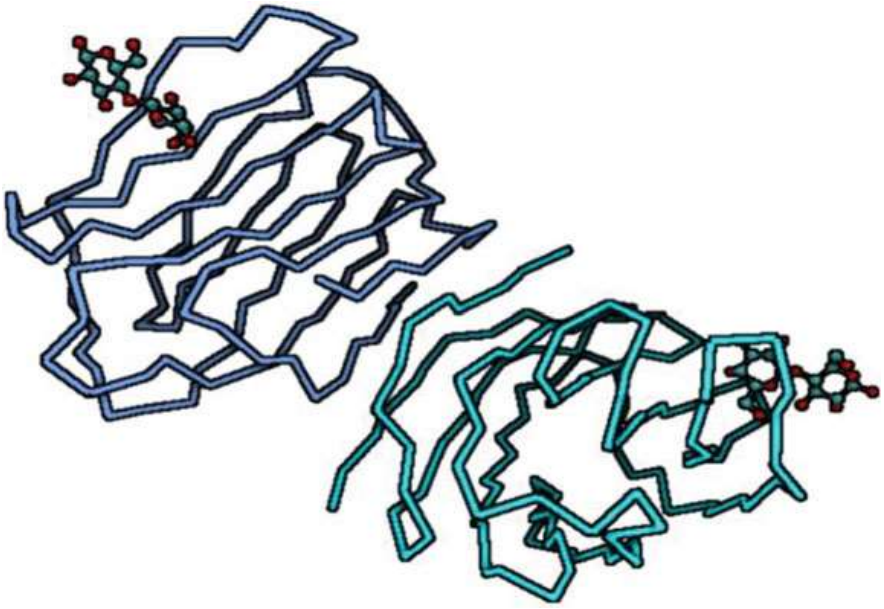


Fig. 4.4 The bound carbohydrate and amino acid side chains in the binding site of the human galectin-2-lactose complex are shown in this diagram

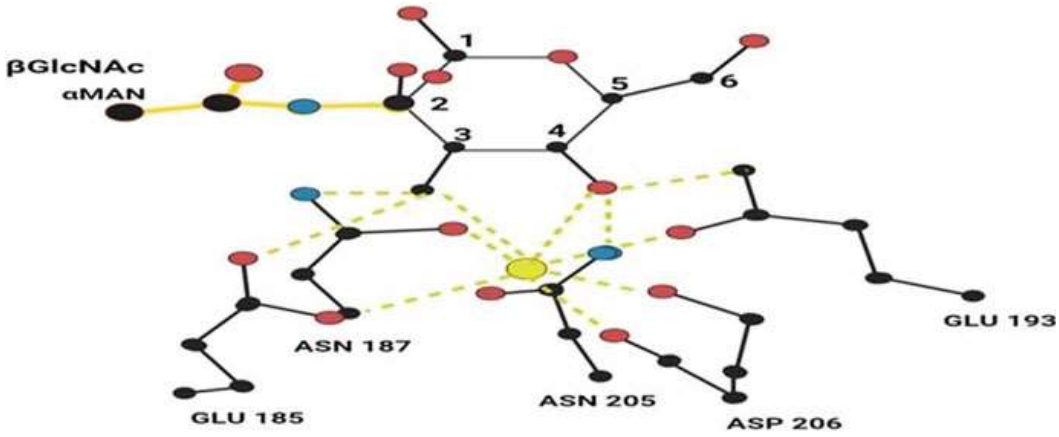


Fig. 4.5 Superimposition of β-*N*-acetyl-D-glucosamine on α-*D*-mannose; numbers on ring carbon atoms are those of both mannose and *N*-acetylglucosamine. (Created with biorender.com)

4.2.3 Bacterial Lectin

Lectins, also known as adhesins, are produced by many bacteria and play a key role in the initiation of infections by mediating adherence to host cells (Qun and Cummings 1993). Other lectins, including those made by bacteria, bind readily to saccharide sequences of cell-surface glycoproteins and glycolipids binding frequently involve not just terminal but also interior carbohydrate sequences (Ofek and Sharon 1988). Bacteria that express surface lectins rapidly bind to phagocytic cells (Sharon 1987). In pathogenic bacteria, lectins are commonly involved in host

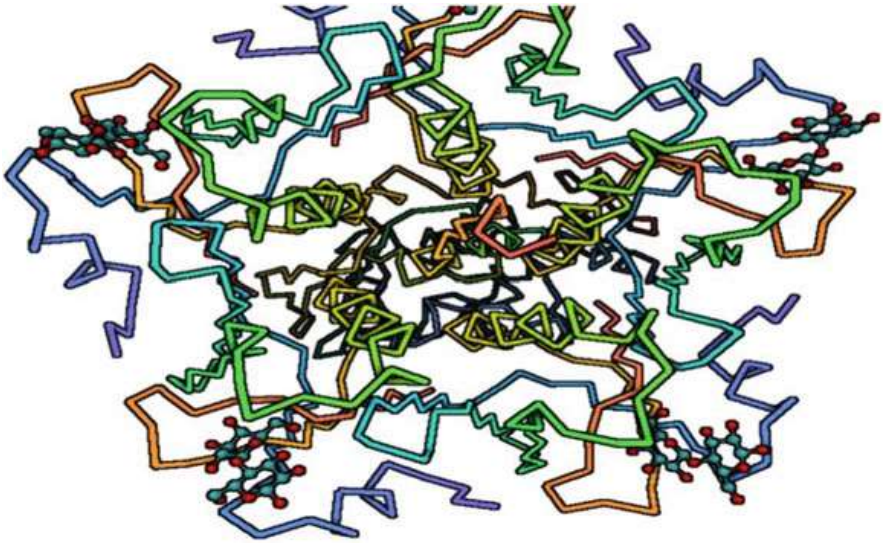


Fig. 4.6 The B-pentamer of the LT-lactose complex, displaying the bound carbohydrate. (Created with biorender.com)

identification and tissue attachment. The importance of carbohydrate-mediated bacterial adhesion in infection has prompted research into bacterial lectin carbohydrate specificity (Perret et al. 2005).

The relevance of carbohydrate-mediated bacterial adhesion in infection has prompted study into the carbohydrate specificity of bacterial lectins, and this study has led to the concept of using carbohydrate antagonists of natural lectin ligands to inhibit bacterial adherence. Site-directed mutagenesis of the carbohydrate-binding component of the sialic acid S-microbial lectin of *Escherichia coli* revealed that replacing Lysl16 with threonine or Argl18 with serine rendered the lectin inactive, implying that ionic interactions are important for the lectin's ability to bind its ligand (Lis and Sharon 1991). The bacterial lectin surface seems to be playing a role of adhesive as seen in infections of the gastrointestinal and urinary tracts. The mannose-specific type-1 fimbriae, galabiose-specific P fimbriae, and *N*-acetylglucosamine-binding F-17 fimbriae, which are produced by distinct strains of Escherichia coli, are the most well-characterized bacterial lectins (Barnes et al. 1999) (Fig. 4.6).

4.3 Molecular Basis of Carbohydrate Interaction

On the basis of mono- and oligosaccharides binding to lectin we divided them into five types which are as follows.

4.3.1 Mannose/Glucose-Binding Lectins

The mannose/glucose-binding lectins are a family of agglutinins found in the *Leguminosae* plant family. The mannose/glucose-specific lectins can be divided into two groups based on their molecular structure: those with four identical subunits (so far only concanavalin A) and those with two light (α) and two heavy (β) chains with the general composition of α2β2, e.g. (Kaku and Goldstein 1992).

A. *Lathyrus tingitanus* (Tangier Pea): This family of lectin binds mannose and glucose. It occurs in α2β2 structure (Bourne et al. 1990). The light and heavy subunits' *N*-terminal amino acids are valine and threonine, respectively. Acidic and alkaline hydroxylic amino acids are found in abundance, but only traces of sulfur-containing amino acids (Rougé and Chabert 1983).
B. *Pisum sativum* (Pea): Van Wauwe and colleagues investigated the carbohydrate-binding specificity of pea lectins in depth. These researchers discovered that configurationally similar monosaccharides, such as mannose, glucose, fructose, and L-sorbose, bind to the lectin by hapten suppression of the precipitation reaction between the *Pisum sativum* lectin and *Pichia pinus* O-phosphonomannan (Van Wauwe et al. 1975).

4.3.2 N-*Acetylglucosamine-Binding Lectins*

N-acetylglucosamine-binding lectins are a broad category of proteins that bind to *N*-acetylglucosamine. With a monosaccharide-specific primary specificity (chitin oligosaccharides) and/or its β-(l→4)-linked oligomers, glucosamine is used in various cases.

A. *Brachypodium sylvaticum* (False Brome Grass): Embryos from Brachypodium sylvaticum contain a blood group-nonspecific lectin with physicochemical features similar to wheat germ agglutinin and other cereal lectins. The *B. sylvaticum* lectin is a dimer ($M_r = 36{,}000$) made up of identical subunits with $M_r = 18{,}000$. It was isolated on a column of immobilized *N*-acetylglucosamine. Only *N*-acetylglucosamine reduced the hemagglutination reaction with erythrocytes among the monosaccharides examined; chitin oligomers were far more efficient (Peumans et al. 1982).
B. *Phytolacca americana* (Pokeweed, Pigeon Berry): Hemagglutination inhibition assay and quantitative inhibition of purified glycoproteins were used to investigate the carbohydrate-binding specificity of pokeweed mitogens. The data show that the pokeweed mitogen isolectins bind to →3Galβ1,4GlcNAcβ1 > or →4GlcNAcβ1,4GlcNAcβ1 (Irimura and Nicolson 1983).

4.3.3 N-*Acetylgalactosamine/Galactose-Binding Lectins*

N-acetylgalactosamine/galactose-binding lectins are the first plant haemagglutinins to be examined, the first to be demonstrated to exhibit human blood group specificity and the most diversified in terms of taxonomic classification. Because the *N*-acetylgalactosamine/galactose-binding lectins have such a wide range of binding activities, we have decided to break down the individual lectins in this group by their monosaccharide specificities (Cherayil et al. 1990). The *N*-acetylgalactosamine-specific lectins will be presented first, followed by proteins that have no preference for either monosaccharide, and finally, proteins that have no preference for either monosaccharide. The high degree of sequence homology among *N*-acetylgalactosamine/galactose-binding lectins indicates that they have structural similarities (Liener 2012).

A. *Phaseolus lunatus syn. Limensis* (Lima Bean): The lima bean agglutinin is the first lectin to be found to have blood group specificity (Boyd and Reguera 1949). It agglutinates type A erythrocytes. The integrity of the free sulfhydryl groups is critical for the haemagglutinating activity of lima bean lectins. *N*-Acetylgalactosamine, a particular lectin inhibitor, protected the lectin from sulfhydryl reagent inactivation (Gould and Scheinberg 1970). The carbohydrate binding site of the lima bean lectin is highly selective. The nature of the interaction between LBL (Lima bean lectin) and the C-2 position of galactose and *N*-acetylgalactosamine using the sulfhydryl group protection assay was also observed. The existence of a hydrophobic area complementary to this aromatic group in the LBL binding site. The lima bean lectin is the most specific of the characterized GalNAc binding lectins for type A blood group material that contains L-fucose: The L-fucose-containing oligosaccharide is only slightly preferred (20%) by the Dolichos biflorus lectin (Etzler and Kabat 1970).
B. *Vicia villosa* (Hairy Vetch): *N*-Acetylgalactosamine is found to be 200 times more effective than galactose as a monosaccharide inhibitor of B4 lectin binding to T. erythrocytes (Tollefsen and Kornfeld 1983). An axial C-4 hydroxyl group and an equatorial *N*-acetyl group at C-2 were also required, as a preference for the α-anomer. The disaccharide GalNAcal,3Gal was shown to be the most effective inhibitor of the precipitin reaction between a mixture of V. villosaisolectins and hog blood mucin, being twice as active as methyl *N*-acetyl-*a*-galactosaminide and twice as active as the α-(l→6)-linked disaccharide (Datta and Basu 1983). The capacity of a succession of glycopeptides to block the binding of Tn erythrocytes, those containing one or two *V. villosa* B4 isolectin terminal *N*-cetyl-galactosamine groups connected to serine or glutamine. The amino acids threonine and arginine were good inhibitors. It is likely that the number and size of the group will grow. The units of *N*-acetylgalactosamine ' positions along the peptide backbone for binding to the B4 isolectin, are crucial.

Fucose specific lectins: Although several fucose-specific legume lectins have been identified, only two have been thoroughly studied in terms of carbohydrate specificity mechanisms: lectin I from gorse *Ulex europaeus*—UEA-I and the lectin from the *Lotus tetragonolobus* (Pace et al. 1999). Binding tests using deoxy-derivatives of L-Fuc α1–2-D-Galβ1–4-DGlcNAc, the highest affinity, provide some evidence. All three fucose hydroxyls were found to be involved in important polar interactions; however, the effect of removing the O2 hydroxyl is less striking. To obtain precise structural information on the molecules, reactivity patterns of fucoglycoconjugates with a panel of fucose-binding lectins were used.

A. *Aleuria aurantia* (Orange Peel Fungus): The haemagglutinin's composition is characterized by high quantities of serine and glycine, as well as the absence of sulfur-containing amino acids and carbohydrates. Each subunit appears to contain one binding site for L-fucose.
B. *Lotus tetragonolobus* (Asparagus Pea): With the multivalent fucose-binding protein, this trivalent dye can produce a three-dimensional lattice precipitate. Ion-exchange chromatography and dialysis were used to remove the dye and monosaccharide after dissolving the precipitate with L-fucose. Fucoglycopeptides having N-linked glycan units can also be bound by Lotus tetragonolobus lectins. Susz and Dawson (1979) found that 6-*O*-*α*-L-fucosyl-*N*-acetylglucosamine is twice as effective as 2′-O-*α*-L-fucosyllactose as a lectin inhibitor, and that an asparagine-linked glycopeptide of this strong disaccharide binds very effectively to a lectin-sepharose adsorbent. Another research (Debray et al. 1981) conducted a comprehensive investigation on the potential of N-linked glycopeptides to suppress lectin-induced hemagglutination, confirming previous findings and emphasizing that glycans with numerous nonreducing terminal a-L-fucosyl units interact with the lectin the best.

4.4 Importance of Lectin–Carbohydrate Interaction

Protein–carbohydrate interactions are crucial in a wide range of biological entities, and many processes rely on them, including infection, fertilization, inflammation, and cellular recognition. The galactose- and GalNAc-terminated oligosaccharides that arise after desialylation of senescent complex-type glycoconjugates are specific for the C-type lectin ASGPR (asialoglycoprotein receptor). The ASGPR trimer binds to triantennary N-linked glycans with great affinity, causing their endocytosis. ASGPR appears to play a role in the clearance of serum glycoproteins in general (Meier et al. 2000). Long-distance feed-back loops connect cell signaling receptors that regulate cell growth and motility. Long-distance loops are part of a complicated regulatory network that includes several glycoprotein glycoforms and molecular communication pathways mediated by lectin–carbohydrate interactions (Zelensky and Gready 2005).

Lectin–carbohydrate interaction plays an important role in receptor-mediated endocytosis of glycoproteins, whereas others, such as the selectins, play a role in cellular recognition and adhesion. Many animal lectins have biological functions that are well understood. A number of mammalian lectins, for example, are engaged in glycoprotein receptor-mediated endocytosis, whereas others, such as the selectins, are involved in cellular recognition and adhesion. The galectin family has been linked to a variety of diseases. Controlling cell growth, activating inflammatory cells, and regulating apoptosis are all aspects of metastasis (Barondes et al. 1994b).

When lectins connect to cells, particular glycoprotein and glycolipid receptors are frequently cross-linked and aggregated. The mitogenic activities of lectins, the activation of mating events in fungi, and the induction of apoptosis in activated human T lymphocytes are all examples of cross-linking interactions that are linked to signal transduction effects. These molecular interactions aid in analyzing diverse range of lectins and their carbohydrate ligands, thereby investigating the corresponding metabolic pathways and their role in various diseases and diagnostics.

4.5 Conclusion

In conclusion we evaluate the interaction between protein-side chains and pyranose forms of the most prevalent monosaccharides discovered among all high-resolution protein-carbon complex structures. Collecting 3D carbohydrate–protein complex structure information offers the basis for biomolecular engineering, design and molecular recognition process modulation of pharmaceuticals. When binding to several lectins, the carbohydrate chains assume various configurations. In interactions with proteins such conformational multiplicities and lower affinities are unique yet difficult to deal with in both practical and theoretical ways in carbon–protein interaction systems. This combination of experimental and theory methods provides fundamental insight into the molecular processes involved in carbon-protein interactions and, at the same time, carbohydrate–carbohydrate interactions, resulting in new concepts for the development of drugs that targeted neurodegenerative and currently incurable disorders.

Acknowledgements We are grateful for the kind support from PG Research & Department of Biotechnology and Microbiology National College (Autonomous), Tiruchirappalli, Tamil Nadu, India.

Conflict of Interest The authors have no conflict of interest to declare.

References

Ambrosi M, Cameron NR, Davis BG (2005) Lectins: tools for the molecular understanding of the glycocode. Org Biomol Chem 3:1593–1608

Barnes YC, Skelton TP, Stamenkovic I, Sgroi DC (1999) Sialylation of the sialic acid binding lectin sialoadhesin regulates its ability to mediate cell adhesion. Blood 93:1245–1252

Barondes SH, Castronovo V, Cooper DNW et al (1994a) Galectins: A family of animal β-galactoside-binding lectins. Cell 76:597–598

Barondes SH, Cooper DN, Gitt MA, Leffler H (1994b) Galectins. Structure and function of a large family of animal lectins. J Biol Chem 269:20807–20810

Bourne Y, Mazurier J, Legrand D et al (1994) Structures of a legume lectin complexed with the human lactotransferrin N2 fragment, and with an isolated biantennary glycopeptide: role of the fucose moiety. Structure 2:209–219

Bourne Y, Roussel A, Frey M et al (1990) Three-dimensional structures of complexes of Lathyrus ochrus isolectin I with glucose and mannose: fine specificity of the monosaccharide-binding site. Proteins 8:365–376

Boyd WC, Reguera RM (1949) Hemagglutinating substances for human cells in various plants. J Immunol 62:333–339

Cherayil BJ, Chaitovitz S, Wong C, Pillai S (1990) Molecular cloning of a human macrophage lectin specific for galactose. Proc Natl Acad Sci U S A 87:7324–7328

Chervenak MC, Toone EJ (1995) Calorimetric analysis of the binding of lectins with overlapping carbohydrate-binding ligand specificities. Biochemistry 34:5685–5695

Datta TK, Basu PS (1983) Human erythrocyte specific lectin from the seeds of Indian coral tree, Erythrina variegata Linn, var. orientali Linn, Merrill. J Biosci 5:25–30

Davey RA, Dudman WF (1979) The carbohydrate of storage glycoproteins from seeds of Pisum sativum: characterization and distribution on component polypeptides. Functional Plant Biol 6: 435

Debray H, Decout D, Strecker G et al (1981) Specificity of twelve lectins towards oligosaccharides and glycopeptides related to N-glycosylproteins. Eur J Biochem 117:41–55

Drickamer K, Fadden AJ (2002) Genomic analysis of C-type lectins. Biochem Soc Symp 69:59–72

Endo Y, Tsurugi K (1987) RNA N-glycosidase activity of ricin A-chain. Mechanism of action of the toxic lectin ricin on eukaryotic ribosomes. J Biol Chem 262:8128–8130

Etzler ME, Kabat EA (1970) Purification and characterization of a lectin (plant hemagglutinin) with blood group A specificity from Dolichos biflorus. Biochemistry 9:869–877

Gould NR, Scheinberg SL (1970) Isolation and partial characterization of two anti-A hemagglutinins from P. lunatus. Arch Biochem Biophys 137:1–11

Gupta D, Oscarson S, Raju TS et al (1996) A comparison of the fine saccharide-binding specificity of Dioclea grandiflora lectin and concanavalin A. Eur J Biochem 242:320–326

Irimura T, Nicolson GL (1983) Interaction of pokeweed mitogen with poly(N-acetyllactosamine)-type carbohydrate chains. Carbohydr Res 120:187–195

Kaku H, Goldstein IJ (1992) Interaction of linear manno-oligosaccharides with three mannose-specific bulb lectins. Comparison with mannose/glucose-binding lectins. Carbohydr Res 229: 337–346

Kennedy JF, Palva PMG, Corella MTS et al (1995) Lectins, versatile proteins of recognition: a review. Carbohydr Polym 26:219–230

Kilpatrick D (2002) Animal lectins: a historical introduction and overview. Biochim Biophys Acta Gen Subj 1572:187–197

Kolatkar AR, Weis WI (1996) Structural basis of galactose recognition by C-type animal lectins. J Biol Chem 271:6679–6685

Liener IE (1976) Phytohemagglutinins (Phytolectins). Annu Rev Plant Physiol 27:291–319

Liener I (2012) The lectins: properties, functions, and applications in biology and medicine. Elsevier

Lis H, Sharon N (1991) Lectin-carbohydrate interactions. Curr Opin Struct Biol 1:741–749

Lord MJ, Jolliffe NA, Marsden CJ et al (2003) Ricin. Mechanisms of cytotoxicity. Toxicol Rev 22: 53–64

Loris R (2002) Principles of structures of animal and plant lectins. Biochim Biophys Acta 1572: 198–208

Meier M, Bider MD, Malashkevich VN et al (2000) Crystal structure of the carbohydrate recognition domain of the H1 subunit of the asialoglycoprotein receptor. J Mol Biol 300:857–865
Ofek I, Sharon N (1988) Lectinophagocytosis: a molecular mechanism of recognition between cell surface sugars and lectins in the phagocytosis of bacteria. Infect Immun 56:539–547
Pace KE, Lee C, Stewart PL, Baum LG (1999) Restricted receptor segregation into membrane microdomains occurs on human T cells during apoptosis induced by galectin-1. J Immunol 163: 3801–3811
Pavelka M, Ellinger A (1989) Affinity cytochemical differentiation of glycoconjugates of small intestinal absorptive cells using Pisum sativum and Lens culinaris lectins. J Histochem Cytochem 37:877–884
Perret S, Sabin C, Dumon C et al (2005) Structural basis for the interaction between human milk oligosaccharides and the bacterial lectin PA-IIL of Pseudomonas aeruginosa. Biochem J 389: 325–332
Peumans WJ, Spaepen C, Stinissen HM, Carlier AR (1982) Isolation and partial characterization of a lectin from a false brome grass (Brachypodiumsylvaticum). Biochem J 205:635–638
Pohleven J, Obermajer N, Sabotic J et al (2009) Purification, characterization and cloning of a ricin B-like lectin from mushroom Clitocybenebularis with antiproliferative activity against human leukemic T cells. Biochim Biophys Acta 1790:173–181
Quiocho FA (1989) Protein-carbohydrate interactions: basic molecular features. Pure Appl Chem 61:1293–1306
Qun Z, Cummings RD (1993) L-14 lectin recognition of laminin and its promotion of in vitro cell adhesion. Arch Biochem Biophys 300:6–17
Rao VSR, Lam K, Qasba PK (1998) Three dimensional structure of the soybean agglutinin-gal/GalNAc complexes by homology modeling. J Biomol Struct Dyn 15:853–860
Rojo J, Morales JC, Penadés S (2002) Carbohydrate-carbohydrate interactions in biological and model systems. In: Penadés S (ed) Host-guest chemistry. Springer, Berlin Heidelberg, pp 45–92
Rougé P, Chabert P (1983) Purification and properties of a lectin from *Lathyrus tingitanus* seeds. FEBS Lett 157:257–260
Rutenber E, Katzin BJ, Ernst S et al (1991) Crystallographic refinement of ricin to 2.5 A. Proteins 10:240–250
Rutenber E, Robertus JD (1991) Structure of ricin B-chain at 2.5 A resolution. Proteins 10:260–269
Sharon N, Lis H (1989) Lectins as cell recognition molecules. Science 246:227–234
Sharon N, Lis H (1972) Lectins: cell-agglutinating and sugar-specific proteins. Science 177:949–959
Sharon N, Lis H (1990) Legume lectins--a large family of homologous proteins. FASEB J 4(14):3198–3208
Sharon N, Lis H (2001) The structural basis for carbohydrate recognition by lectins. Adv Exp Med Biol 491:1–16
Sharon N, Lis H (2013) Lectins. In: Encyclopedia of biological chemistry. Elsevier, pp 701–705
Sharon N (1987) Bacterial lectins, cell-cell recognition and infectious disease. FEBS Lett 217:145–157
Sumner JB, Howell SF (1936) Identification of Hemagglutinin of Jack Bean with concanavalin A. J Bacteriol 32:227–237
Susz JP, Dawson G (1979) The affinity of the fucose-binding lectin from Lotus tetragonolobus for glycopeptides and oligosaccharides accumulating in fucosidosis. J Neurochem 32:1009–1013
Tollefsen SE, Kornfeld R (1983) The B4 lectin from Vicia villosa seeds interacts with N-acetylgalactosamine residues alpha-linked to serine or threonine residues in cell surface glycoproteins. J Biol Chem 258:5172–5176
Toone EJ (1994) Structure and energetics of protein-carbohydrate complexes. Curr Opin Struct Biol 4:719–728
Van Den Hamer CJ, Morell AG, Scheinberg IH et al (1970) Physical and chemical studies on ceruloplasmin. IX. The role of galactosyl residues in the clearance of ceruloplasmin from the circulation. J Biol Chem 245:4397–4402

Van Wauwe JP, Loontiens FG, De Bruyne CK (1975) Carbohydrate binding specificity of the lectin from the pea (Pisum sativum). Biochim Biophys Acta 379:456–461

Weis WI, Taylor ME, Drickamer K (1998) The C-type lectin superfamily in the immune system. Immunol Rev 163:19–34

Ye XY, Ng TB, Tsang PW, Wang J (2001) Isolation of a homodimeric lectin with antifungal and antiviral activities from red kidney bean (Phaseolus vulgaris) seeds. J Protein Chem 20:367–375

Zelensky AN, Gready JE (2005) The C-type lectin-like domain superfamily. FEBS J 272:6179–6217

Preetham Elumalai
Sreeja Lakshmi *Editors*

Lectins

Innate Immune Defense and Therapeutics

Springer

Lectins

Preetham Elumalai • Sreeja Lakshmi
Editors

Lectins

Innate Immune Defense and Therapeutics

Springer

Editors
Dr. Preetham Elumalai
Department of Marine Biology, Microbiology and Biochemistry, School of Marine Sciences
Cochin University of Science and Technology
Cochin, Kerala, India

Dr. Sreeja Lakshmi
School of Ocean Science and Technology
Kerala University of Fisheries and Ocean Studies
Cochin, Kerala, India

ISBN 978-981-16-7461-7 ISBN 978-981-16-7462-4 (eBook)
https://doi.org/10.1007/978-981-16-7462-4

© The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature Singapore Pte Ltd. 2021
This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors, and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Preface

Lectins: Innate Immune Defense and Therapeutics focuses on exploring the importance of lectins in immune defense and modern therapeutic approaches. Lectins are protein molecules, widely distributed in different species in almost all organisms including plants, animals, viruses, bacteria, cyanobacteria and yeasts. They serve as receptors for recognizing carbohydrate moieties present on the pathogenic surfaces and exert a specific interaction with them. Following the discovery of animal lectins, research in basic and applied biosciences experienced an accelerated thrust because of its role in mediating cell-cell interactions, host cell-pathogen interactions, antimicrobial activity, drug discovery, etc. Our book is anticipated to provide an overview on different types of lectins and future perspectives in scientific research as recognition and effector molecules in innate immunity or regulators of adaptive immune responses. We really appreciate the contributions of the authors for their expertise and skilful renditions. The facts about Lectins presented in this book will provide an overview to newcomers and a meticulous illustration to the specialists in the field.

Cochin, Kerala, India

Preetham Elumalai
Sreeja Lakshmi

Contents

1 **Overview of Lectins** 1
M. S. Prachi Vibhute, Mohamed Jaabir, S. Sangeetha Bharath, and Jeyachandran Sivakamavalli

2 **Structure, Biosynthesis, and Biological Properties of Lectins** 27
N. S. Kaviyarasi

3 **Classification of Lectins** 51
Akshaya Radhakrishnan, Kiyun Park, Ihn-Sil Kwak, Mohamed Jaabir, and Jeyachandran Sivakamavalli

4 **Molecular Basis of Lectin–Carbohydrate Interaction** 73
Yashika Pusam, Mohamed Jaabir, and Sivakamavalli Jeyachandran

5 **Animal Lectin** 89
Sahya Narayanan, Akhila Raj Pallan, Akshay Balakrishnan, Eldho J. Paul, and Preetham Elumalai

6 **Plant Lectins** 107
Abdullah Bin Abdul Nazar, Aneetta Skinner, Debarghya Ghosh Dastidar, and Preetham Elumalai

7 **Microbial Lectins** 131
Abdul Salam Rubeena, Abigith Abraham, and K. M. Aarif

8 **Regulation of Immune Responses by Lectins** 147
Shamna Naseemashahul and Femi John Fawole

9 **Lectin–Carbohydrate Interactions in Pathogenesis** 165
Anbazhagan Veerappan and Siva Bala Subramaniyan

10 Lectins in Health and Diseases: Mannan-Binding Lectin and Infectious Diseases 185
Sadhana Sharma, Pankaj Kumar Patel, Komal Choudhary, Parija P. Phadnavis, Sonali R Bhagwat, Sumati Hajela, Abhilasha, Rajesh Kumar Gupta, and Krishnan Hajela

11 Lectins in Health and Diseases: Galectins and Cancer 215
Shirsha Nandi, Sayantani Ghosh, Amit Ranjan, Rajkumar S. Sood, Jayanta K. Pal, Krishnan Hajela, and Rajesh Kumar Gupta

12 Lectins in Diagnostic Tools and Therapeutic Agents 273
Mani Divya, Sekar Vijayakumar, and Baskaralingam Vaseeharan

13 Modern Approach in Lectin-Based Nanomedicine 285
Arivarasan Vishnu Kirthi, Loganathan Karthik, and Babu Gajendran

Chapter 3
Classification of Lectins



Akshaya Radhakrishnan, Kiyun Park, Ihn-Sil Kwak, Mohamed Jaabir, and Jeyachandran Sivakamavalli

Abstract Recent progress in biochemistry and structural biology has identified enormous proteins which specifically bind with carbohydrates and mediate various significant physiological processes. Such proteins termed as lectins can be classified into various categories based on their molecular structure, carbohydrate recognition domain, binding specificity, source of synthesis, and evolutionary relationship. Lectins are widely present in plants, animals, and microbial organisms and are classified into several types based on their evolutionary and structural similarity. Based on their molecular and structural aspects lectins are classified into simple, mosaic, and macromolecular complexes. Also mashed on the carbohydrate recognition domain, lectins could be classified into hololectins, merolectins, chimera lectins, and superlectins. All these categories of lectins can be correlated with their specificity towards glycoconjugate moieties of which the most specific ones being mannose, galactose/N-acetylgalactosamine, fucose, and sialic acid specific lectins. This classification enables successful identification and characterization of novel lectins with significant biological applications.

Keywords Carbohydrate-binding protein · Carbohydrate recognition domain · Legume · Galectins · C-lectins · Haemagglutinin

Abbreviations

ASGPR	Asialoglycoprotein receptor
CBD	Carbohydrate-binding domain
CD-MPR	Cation-dependent mannose 6-phosphate receptor
ConA	Concanavalin A
CRD	Carbohydrate recognition domain

A. Radhakrishnan · M. Jaabir · J. Sivakamavalli (✉)
PG Research and Department of Biotechnology, National College, Trichirappalli, India

K. Park · I.-S. Kwak
Fisheries Research Institute, Chonnam National University, Yeosu, South Korea

© The Author(s), under exclusive license to Springer Nature Singapore Pte Ltd. 2021

P. Elumalai, S. Lakshmi (eds.), *Lectins*,
https://doi.org/10.1007/978-981-16-7462-4_3

CRP	C-reactive protein
CTLD	C-type lectin-like domains
ER	Endoplasmic reticulum
ERGIC-53	ER-Golgi intermediate compartment 53 kDa protein.
ERGL	ERGIC-53-like
FP	Pentraxin family
FTLD	Fucose recognition lectin domain
Gal	Galactose
GalNac	N-acetylgalactosamine
GIT	Gastrointestinal tract
IGF-II/MPR	Insulin-like growth factor II/mannose 6-phosphate receptor
LacNac	N-Acetyllactosamine
Man	Mannose
M6P	Mannose 6 phosphate
MMBL	Monocot mannose-binding lectin
MPR	Mannose 6-phosphate receptor
MRH	Mannose 6-phosphate receptor homology
Neu5Ac	N-glycolylneuraminic acid
PTX3	Long pentraxin 3
RCA	*Ricinus communis* agglutinin
RIP	Ribosome-inactivating protein
SAP	Serum amyloid protein
SBA	Soybean
WGA	Wheat germ agglutinin

3.1 Introduction

Lectins are a type of glycoprotein abundant in nature that binds to monosaccharide and oligosaccharide residues with specific structure and configuration. In general, all lectin molecules possess two or more carbohydrate-binding sites, which is required for them to agglutinate cells or glycoconjugates (Goldstein and Hayes 1978). Lectins are a structurally diverse class of proteins distinguished by their ability to specifically bind carbohydrate moieties of cell surface glycoproteins. Lectin can be obtained from plants, microbials, or animals and can be soluble or adherent to membranes. In 1888, the characteristic feature of castor bean seed (*Ricinus communis* L.) extract to agglutinate animal red blood cells led to the discovery of lectins primarily in plants. Following that, similar "agglutinins" were discovered in the seeds of several plants, most commonly in leguminous plants and were renamed lectins as they could differentiate human ABO blood types, significant for blood transfusions (Tsaneva and Van Damme 2020). The asialoglycoprotein receptor (ASGPR), discovered by Anatol Morell and Gilbert Ashwell in the late 1960s while analyzing the transition of a serum glycoprotein called ceruloplasmin, was the first animal lectin found (Hudgin

et al. 1974). Bacterial surface lectins were discovered in the 1970s by Nathan Sharon and colleagues. Along with their haemagglutinating action, the major role of microbial lectins is to provide adhesion to host cells, which is essential for colonization and pathogenicity (Sharon and Lis 2004).

Lectins attach to simple or complex carbohydrate conjugates in a reversible and noncovalent manner, whether free in solution or on cell surfaces. The glycoconjugate-containing surface will only function as a lectin receptor. The specificity of lectins is typically determined using a hapten inhibition test, in which different sugars are evaluated for their ability to block erythrocyte hemagglutination. All lectin molecules have two or more carbohydrate-binding sites, which is required for them to agglutinate cells or react with complex carbohydrates. These molecules will bind hydrophobically, although electrostatic forces are rarely involved. Lectins have been isolated from crude aqueous solutions or saline buffers of diverse tissues using conventional protein extraction techniques. These include the utilization of ammonium sulfate or ethanol precipitation, as well as affinity chromatography (Helliwell 1998). The structural diversity aided upon by their specific carbohydrate-binding properties provides them with a wide range of biological functions in plants, animals, and microbes. Numerous investigations have been done to demonstrate such biological effects of lectins. One such demonstration is the in vitro analysis of the action of lectins on lymphocyte mitogenesis, both activation and inhibition, with lymphocytes from the gastrointestinal tract (GIT) being the most sensitive. It was also found that lectins can agglutinate immunoglobulins, activate the alternative complement system, limit fungal development, and stimulate histamine release from immune cells.

Lectins are resistant to both heat (at 70 °C for more than 30 min) and digestion. Some lectins are extremely resistant to gastrointestinal acids and enzymes (Shah and Rocca 2004). Also, lectins are essential components of biological processes such as cell signal transduction, cell–cell communication, and host–pathogen recognition. Host cell receptors which attach to pathogens are frequently glycan-recognizing complexes like lectins, and the interactions between such lectins and carbohydrate epitopes on the pathogens initiate infection. Hence identification and classification of diverse types of lectins that aid in these processes are therefore critical for effective development of diagnosis and treatments. For example, lectins can act as potential biomarkers in cancer tissues, assisting in the early diagnosis of cancer (Wu et al. 2012). Lectins can be classified into various groups based on their molecular structure, carbohydrate specificity, variance in carbohydrate-binding domain, and their localization within different forms of life including plants, animals, and microbes which imparts their specific biological functions. Lectins are often categorized using carbohydrates as the sensor, with the identification principle relying on the strength of interactions between a carbohydrate ligand and its binding lectin. Lectins are generally classified into five categories based on their affinity towards the monosaccharide substrates such as mannose, galactose/N-acetylgalactosamine, fucose, N-acetylglucosamine, and N-acetylneuraminic acid. The abundance of such monosaccharides as components of typical glycans seen on the surface of eukaryotic cells in nature supports the relevant biological activities of lectins.

Hundreds of lectins have been identified and categorized using affinity chromatography and recombinant DNA methods on immobilized carbohydrates (Hamid et al. 2013).

The characterization of the amino acid sequences of dozens of lectins, along with the identification of around 30 3D structures, has permitted a classification based on shared molecular and structural characteristics. On that basis, the majority of lectins are classified into three types: (1) simple, (2) mosaic (or multidomain), and (3) macromolecular complexes (Van Damme et al. 1998). Lectin proteins possess at least one carbohydrate-binding domain which involves in specific glycoconjugate binding and on that basis, lectins could also be classified as merolectins (single carbohydrate-binding domain—monovalent), hololectins (at least two binding domain that binds structurally same sugar), chimerolectins (one or more C-binding domain with a specific enzymatic activity), and superlectins (binds structurally unrelated sugars) (Damme et al. 1998). In the aspect of species classification aided by structural and binding characteristics, the vast majority of known plant lectins may be divided into seven structurally and evolutionarily associated protein families such as the amaranthin family (amaranthins), the chitin-binding enzymes lectins with the vein domains, phloem lectins from Cucurbitaceae, jacalin-related lectins, legume lectins, monocot mannose-binding lectins (MMBL), and ribosome-inactivating proteins of type 2 (type 2 RIP) (Peumans et al. 2001). Animal lectins are classified into several families, depending on their diverse cellular localization and the binding specificities of their carbohydrate recognition domain (CRD) modules. Earlier characterization of animal lectins is classified them into two principal structural families, the C-type (Ca^{2+} dependent binding) and S-type-galectins (sulfhydryl dependent binding) lectins. The C-type lectin family has become a highly significant group, wherein about 17 classes of proteins have been identified with their structural and genomic analysis (Drickamer and Fadden 2002). In case of microbes, the lectin interactions are utilized to identify bacteria, fungi, and protozoa. Bacterial lectins are similar to carbohydrate-binding characteristics and relative stability of plant lectins (Chesterton 1987). The first lectins on the bacterial surface were reported in the 1970s by Nathan Sharon and his colleagues. The main function of these lectins in microbes is to promote the adhesion or adherence of the bacteria to the host cells. Bacterial lectins are hence commonly referred to as adhesions, which attach corresponding glycan receptors on the host cell surface via carbohydrate recognition domains (CRDs). The ability of these microbial lectins to aggregate or cause the hemagglutination of red blood cells was the basis for their discovery and is termed haemagglutinin. Bacteria may also synthesize soluble toxins, which rely on glycoconjugate-binding subunits to interact with membrane glycoconjugates and transport the functionally active toxic component through the membrane. Many microbial agglutinins, adhesins, and toxins have been identified, cloned, and characterized in the last 30 years (Nizet et al. 2015). The classification of these diverse lectins in terms of various aspects makes it easier to analyze over a wide range of potential applications dependent on their molecular and evolutionary characteristics.

3.2 Classification of Lectins Based on Molecular Structure

Lectins can be categorized into structurally and evolutionarily related protein families based on their amino acid sequence and molecular structure. And in that aspect, most, but not all, members of that particular lectin family are composed of monomers with a homologous basic structure and overall three-dimensional orientation. The basic structure of lectins is influenced not only by the structure of monomers, but also by the degree of polymerization and, in certain circumstances, the post-translational modification also matters (Damme et al. 1998). The three-dimensional topologies of known lectin structures vary widely. The simultaneous functions of subunit location and multivalency, however, provide a paradigm for understanding the structural basis of lectin–carbohydrate interactions (Rini 1995). The majority of lectins fall into one of the three categories: simple, mosaic or multidomain, and macromolecular complexes on the basis of their structure.

3.2.1 Simple Lectins

Simple lectins are composed of a limited number of subunits, all of which are not exactly identical and have a molecular weight of less than 40 k Da. A carbohydrate-binding site is present in each monomeric unit. Almost all known plant lectins and most members of the galectin family of animal lectins, a group of β-galactoside specific animal lectins, fall into this category. Major types of lectins classified under simple lectins include legume, cereal, Amaryllidaceae and related families, Moraceae, Euphorbiaceae, Galectins, and Pentraxins (Lis and Sharon 1998).

3.2.1.1 Legume

Leguminous lectins are a wide group of carbohydrate-binding proteins that are primarily found in legumes. The discovery of *Phaseolus vulgaris* (bean), *Lens culinaris* (lentil), *Vicia sativa* (vetch), *Pisum sativum* (pea) in legumes by Landsteiner and Raubitzchek proved that non-toxic lectins exist among the period with toxic lectins (Landsteiner and Raubitschek 1907). Seed lectins make up a large portion of legume lectins. Some are also present as vegetative tissues such as leaves and bark. Such seeds or vegetative tissues contain two or more distinct lectins. Legume lectins are composed of 30 kDa protomers generated from homologous primary translation components containing about 250 amino acid residues. Most legume lectin protomers are composed of a single polypeptide chain of around 250–300 amino acid residues. Legume lectins were essentially utilized in the fields of plant lectin biochemistry, physiology, and molecular biology research. Legume lectins have the ability to interact with both simple and complex carbohydrates. The carbohydrate-binding specificity of the various lectins in the legume lectin family is extremely

diverse. Hence, legume lectins cover a far larger spectrum of binding specificities than any other lectin family (Young and Oomen 1992). Concanavalin A was the first plant lectin to be isolated, crystallized, and subjected to X-ray diffraction analysis. The soybean seed lectin was the first plant lectin to be cloned, which is a legume lectin (Hardman and Ainsworth 1972).

3.2.1.2 Amaranthin

The lectins known as "amaranthin" are discovered in the seeds of Amaranthus species. The family is called "amaranthin" after the substantive name of the first member of this family that was isolated from *Amaranthus caudatus* seeds. Other species with this lectin involve *A. spinosus, A. caudatus, A. leucocarpus, and A. cruentus*. Amaranthins are defined by their tiny protomers of size about 12–33 kDa, along with three-fold internal repeats built upon 36 amino acids, characterized by the lack of metal action, and poor affinity for the carbohydrate ligand (Chervenak and Toone 1995). Such agglutinin protomers are made up of two domains (the N- and C-domains) connected by a short helix (Transue et al. 1997). Amaranthin is often thought to be a GalNAc-specific lectin although it has a far greater affinity to the GaIB(1,3) GaINAc T-antigen disaccharide. This selectivity implies that amaranthins are intended to also encounter the common animal glycoconjugates (Rinderle et al. 1989). Recent research also proves the potential applications of amaranthin lectin for their antiproliferative activity through exerting a cytotoxic effect that would promote apoptosis (Quiroga et al. 2015).

3.2.1.3 Cereal–Wheat Germ Agglutinin

A variety of lectins can be found in high quantities in dietary staples, such as cereal grains. Lectin activity has been reported in wheat, rice, barley, oats, and corn but WGA is the cereal grain lectin that has received the most attention. Wheat germ agglutinin (WGA) is a lectin found in wheat germ that are of great significance (Cordain 1999). This lectin is a homodimer composed of monomeric subunits. Each protomeric unit of wheat germ agglutinin is composed of four structurally similar domains that share a high degree of amino acid sequence identity. Such domains possess four interconnecting disulfide linkages, within each, that enables a compact protein structure (Goldstein et al. 1997). WGA attaches to the sialic acid present mostly in humans, allowing it to cling to cell surfaces such as the gut epithelial layer (Shaw et al. 1991). The binding of WGA to Neu5Ac in the glycocalyx of human cells and pathogens that produce Neu5Ac further leads to cell invasion and perhaps disrupting immunological tolerance by eliciting pro-inflammatory immune stimuli (Varki 2009).

3.2.1.4 Moraceae–Jacalin

Jacalin lectins were identified, in fact, solely in *Artocarpus* and *Maclura pomifera* seeds and some vegetative tissues (de Azevedo Moreira and Ainouz 1981). On the basis of lectin specificity, they are distinguished into the tiny GalNAc-specific Moraceae lectins and the extended mannose-specific jacalin lectins. These lectins possess mannose-binding specificity and, however, are extensively spread among higher plants. Each Moraceae lectin galactose-specific has four identical, large α-chain and short β-chain protomers that consist of a single sugar-binding site. All known jacalin-related mannose lectins are made up of extremely identical protomers containing around 120–150 residues of amino acid (Sankaranarayanan et al. 1996). The significance of the finding of these novel lectins became obvious when it was discovered that these novel lectins also selectively bind GalB(1,3)GalNAc-residues. Jacalin was widely utilized as a potent immunological tool when its particular IgA-binding activity and mitogenicity were also reported (Skea et al. 1988).

3.2.1.5 Euphorbiaceae–Chitin-Binding Lectins

The chitin-binding lectins are a large and diverse family of proteins that include all proteins with at least one hevein domain (43-amino acid protein that contains a highly integrated chitin-binding site). Chitin-binding lectins with hevein domains are quite common in plants. For example, single hevein domain proteins were purified from *Hevea brasiliensis* (Euphorbiaceae) (Walujono et al. 1975). Other lectins of the family involve beans of the castor tree (*Ricinus communis*) that comprise two closely related lectins, ricin and *Ricinus communis* agglutinin, RCA. Ricin is a 60 kDa heterodimeric protein composed of two S-S linked chains, A and B. B chain possesses galactose-specific carbohydrate-binding sites whereas cytotoxic action is found in the A chain (Macholz 1988). By affinity chromatography on cross-linked arabinogalactan, a N-acetylgalactosamine-specific lectin was isolated from Euphorbia heterophylla seeds. Its distribution over the seed is normal in the regard that it is mostly limited to the main axes (Nsimba-Lubaki et al. 1983).

3.2.1.6 Galectins

Galectins or S-type lectins are soluble β-galactosidase binding lectins that bind to β-galactosidase independent of Ca^{2+}. It functions based on conserved amino acid residues that are similar to those found in the carbohydrate-binding domain (CRD) (Barondes et al. 1994). These proteins were formerly known as S-type proteins because they required sulfhydryl groups, but were eventually substituted by galectins after site-directed mutagenesis that revealed the existence of some soluble protein groups without sulfhydryl groups (Hirabayashi 1996). About 15 galectins have been characterized by primary structural research analysis up to date, which

vary also in their cellular position, binding affinities, carbohydrate-binding domain, and expression. Further galectins have been classified into three groups such as proto galectins, chimera galectins, and tandem repeat type galectins (Hirabayashi and Kasai 1993). Galectins of the prototype, such as galectin-1,2,7,10,13,14 are characterized by only one CRD that exists as dimers. Whereas the chimera galectin which includes galectin-3 possesses a CRD region at COOH terminal and a non-CRD region at NH2 terminal. Galectins of the tandem repeat type, such as galectin-4,8,9,12, have two CRDs bound by a short linker peptide. Galectin-1 seems to have a strong affinity for complex-type N-glycans, while galectin-3 has a strong affinity for the LacNAc repeats (Nio-Kobayashi 2017).

3.2.1.7 Pentraxins

The pentraxins are a group of simple plasma proteins that play a role in invertebrate and vertebrate innate immunity. They have L-type lectin structures and glycoconjugate ligand binding requires Ca^{2+} ions. C-reactive protein (CRP), serum amyloid protein (SAP), and female protein are three of the most important members of the pentraxin family (FP). Pentraxins are composed of five identical noncovalently bound subunits arrayed in a circular pentameric disc structure. Pentraxins are classified into two categories based on the main structure of the subunit: short pentraxins and long pentraxins (Gupta 2012a). The pentraxins (C-reactive protein, CRP; serum-amyloid P component, SAP; long pentraxin 3, PTX3) are effectively involved in complement activation and amplification via association with other complement factors (Ma and Garred 2018).

3.2.2 Mosaic Lectin

Mosaic lectins are multidomain lectins that possess a wide range of molecular weights and are made up of multiple diverse protein modules or domains, only one of which has a carbohydrate-binding domain (CBD). Virus haemagglutinins and some of the animal lectins such as C-, P-, and I-types are the lectins that come under mosaic lectins. These diverse characteristics impart diverse functionality in their applications.

3.2.2.1 Viral Haemagglutinin

Viruses express a huge range of glycan-binding proteins, which resembles lectins. Initially many of the microbial lectins were recognized based on their capacity to aggregate or cause red blood cell hemagglutination (erythrocytes). Alfred Gottschalk in 1950 reported the first microbial haemagglutinin discovered from the influenza virus that binds erythrocytes and other cells was linked via the sialic acid component

of the host cellular glycoconjugates. This binding promotes the infection of the host and hence contributes to the viral pathogenicity (Wiley and Skehel 1987). Viral haemagglutinin comprises two polypeptides, HA1 and HA2, each of molecular mass 36 kDa and 26 kDa, respectively, which is covalently connected by a single disulfide bond (Nizet et al. 2015). Other such haemagglutinin is found in a non-enveloped, icosahedral symmetrical murine polyoma virus, which possesses a circular, double-stranded DNA genome. The capsid of the virion possesses around 360 copies of the viral protein VP1 (with two antiparallel β sheets) of 42 kDa positioned as pentamers (Stehle and Harrison 1997).

3.2.2.2 C-Lectin

C-type lectins are those which possess a carbohydrate recognition domain (CRD) that links sugars by binding to Ca^{2+} in most cases, making the sugar-binding activity Ca^{2+}-dependent (Weis et al. 1998). As a greater number of proteins were identified, it became evident that not every protein with C-type CRDs would bind glycans and Ca^{2+}. To address the discrepancy, the term "C-type lectin-like domains" (CTLD) was coined for such domains. CRD is often used to refer to the short amino-acid motifs found in CTLDs that interact specifically with Ca^{2+} and carbohydrates (Rivkin et al. 2000). C-Type lectin family has become a highly significant group, wherein about 17 classes of proteins have been identified with their structural and genomic analysis. It is also worth noting that the overall layout of a lectin is dependent on how a CRD interacts with other domains, reflecting the multivalent binding of lectins (Drickamer and Taylor 2015). C-type lectin involves various endocytic receptors, collectins, and selectins which have diverse glycoconjugate specificity. Selectins are a Ca^{2+} dependent receptor family that has been discovered to mediate important cell–cell interactions in a variety of processes such as leukocyte trafficking, inflammation, thrombosis, tissue injury, etc. (Rosen and Bertozzi 1994). Collectins are soluble oligomeric proteins with carboxylic terminal upholding the carbohydrate recognition domain (CRD) and a collagen-like domain with a short cysteine-rich N-terminus which together aids in effective functioning (Drickamer et al. 1986).

3.2.2.3 P-Lectin

The carbohydrate recognition domain (CRD) of these proteins has a high affinity for mannose 6-phosphate, therefore, the name "P-type" lectin family (M6P). The cation-dependent mannose 6-phosphate receptor (CD-MPR) and the insulin-like growth factor II/mannose 6-phosphate receptor (IGF-II/MPR) are two molecules that differentiate the P-type lectin family from others by their capacity to recognize phosphorylated mannose residues (Dahms 2002). Mannose 6-phosphate receptors

(MPRs) are the most used term for them. MPRs serve an important role in the targeting of lysosomal enzymes in vertebrates. On binding affinity analysis, it was found that a single MRH domain in CD-MPR exists as dimers which bind with diverse glycans. Such binding of diverse ligand molecules even non-glycans makes P-Lectins a highly efficient protein involved in various physiological functions such as cell signaling, as biomarkers, etc. (Munro 2001).

3.2.2.4 I-Lectin

I-type lectins are glycan-binding proteins that belong to the immunoglobulin (Ig) superfamily and are classified according to the conserved amino acid residues in the CRD region (Powell and Varki 1995). With their conserved CRD domain I-type lectins mostly bind sialic acid on the cell surface and are termed "Siglecs" which is the most characterized I-lectin. Siglecs consist of an N-terminal variable-set Ig domain with a sialic acid binding site, followed by a constant region Ig domain (Crocker and Varki 2001) and also a conserved arginine residue on the F-strand on V-region is a criterion for ligand binding. In humans, 11 main Siglecs and one Siglec-like molecule have been identified. The CD33-related Siglecs have 4 C-set domains and cytoplasmic tyrosine-residues that are implicated in signaling and endocytosis. It was also demonstrated that Siglec binding specificity may be used to create cell-based glycan arrays that could be beneficial in therapeutic targeting against autoimmune disorders and cancer (Crocker 2002).

3.2.3 Macromolecular Complex

Macromolecular assembly of proteins involves lectin organization with multivalent binding and thus imparts significant functions. Bacteria possess a lot of macromolecular assemblies of lectins that are filamentous organelles made up of helical subunits (pilins) and are assembled in a certain sequence (Ofek and Doyle 1994a). These proteins aid in bacterial adhesion followed by invasion and infection. These lectins are heteropolymeric filamentous organelles. The majority of the lectin is composed of a structural polymer and only a small portion contains the carbohydrate-binding site (Ting et al. 2010). Furthermore, along with their large size and complexity, polysaccharide-lectin complexes may be used as model systems to study inter-polysaccharide and protein-polysaccharide interactions. The macromolecular assemblies of complex polysaccharides with galectin-3, a major lectin, and their synergistic effects on function were described in a study (Zhang et al. 2017).

3.3 Classification of Lectins Based on Glycoconjugate Specificity

Lectins are a type of protein that binds carbohydrates in a specific (Table 3.1) and reversible manner. The wide array of applications they perform is in turn the effect of this specific monosaccharide binding and this varies upon different types of lectins (Sharon and Lis 2007). Lectins can be categorized into different groups based on the monosaccharide for which they have the specificity to bind including mannose, galactose/N-acetylgalactosamine, fucose, and sialic acid specific residues. These monosaccharides are typical glycan components found on the surfaces of eukaryotic cells. Lectins with the same glycoconjugate specificity show varied affinity for oligosaccharides and can only show affinity for oligosaccharide derivatives corresponding to monosaccharides (Sharon and Lis 2013).

3.3.1 Mannose-Specific Lectins

Mannose-specific lectins are extensively distributed throughout higher plants, algae, and fungi and are thought to have a role in the detection of microorganisms and plant predators through their high mannose glycans (Barre et al. 2019). The mannose-binding specificity of lectins is mediated by different structural scaffolds, according to structural analysis. These lectins are made up of several structural scaffold components that contain one or more carbohydrate-binding sites and are important in the recognition of mannose-containing glycans. The mannose-binding site possesses a small carbohydrate-binding region responsible for wider sugar-binding specificity towards mannose molecule, surrounded by a larger binding area that is responsible for the specific recognition of larger mannose-containing N-glycan chains (Barre et al. 2001). In animals, pathogenic species and potentially toxic glycoconjugates are cleared by the macrophage mannose receptor which resembles exogeneous type 1 transmembrane receptor proteins. These receptors are efficient proteins that clear glycoconjugates with terminal mannose residues by selectively binding to them. Mannose-specific binding and internalization lead to lysosomal

Table 3.1 Various lectins and their specific sugar residues

Sugar residue	Lectin	References
Mannose/glucose	ConA Macrophage mannose receptor	Ramkumar et al. (2002)
N-acetyl D-glucosamine	Wheat germ agglutinin Endocytic receptors	Levy (1979)
Fucose	Ulex europaeus agglutinin 1 F-box lectin	Chetty et al. (2016)
Sialic acid	Wheat germ agglutinin	Ryva et al. (2019)
N-acetyl D-galactosamine	Jacalin, Amaranthaceae	Zeng et al. (2019)

destruction, resulting in the elimination of foreign pathogens by the innate immune system (Stahl 1990).

3.3.2 Galactose/N-acetylgalactosamine Specific Lectins

Many C-type animal lectins recognize galactose- or N-acetylgalactosamine oligosaccharides. The best-known Gal-binding C-type lectins are the mammalian hepatocyte asialoglycoprotein receptors, which play a role in serum glycoprotein homeostasis. C-type lectins with a high affinity for glycoconjugates containing terminal galactose and N-acetylgalactosamine residues have also been discovered on the surfaces of macrophages and Kupffer cells and seem to mediate tumor cell recognition. N-acetyl-D-galactosamine lectins are significant in determining sugar moiety in blood group in animals (Kolatkar and Weis 1996). Liener and Pallansch were the first to purify soybean lectin (SBA) specific to galactose and N-acetyl-D-galactosamine in plants. Later, Sharon and colleagues isolated the same lectin using affinity chromatography with a column of 6-aminocaproyl-D-galactosylamine linked to Sepharose. Later various plant lectins such as red kidney bean lectin, horseshoe lectin, Concanavalin A legume lectin were identified with galactose and N-glycan specificity (Yosizawa and Miki 1963).

3.3.3 Fucose Specific Lectins

F-type lectins are fucose-binding proteins that are found in a wide range of taxonomic groups, from viruses, plants, and vertebrates. They possess a fucose recognition lectin domain (FTLD) with a novel fold termed F-type fold consisting of a barrel structure with specific fucose- and calcium-binding motif. Although FTLs can have a single FTLD, which is often coupled with more than one diverse domain in single polypeptide, members of this lectin family can also have a variable number of tandemly distributed FTLDs which mediate the process of binding (Vasta et al. 2017).

3.3.4 Sialic Acid Specific Lectins

Sialic acid binding lectins are those which bind to sialic acids selectively and have the potential to be beneficial in the detection, purification, quantification, and characterization of numerous biomolecules containing sialic acids residues, such as glycoconjugates, gangliosides, and polysaccharides. Such lectins can be utilized as particular probes for specific sialic acid derivatives that act as molecular markers in enormous physiological and biochemical processes (Schauer 1983). Limulin is a

significant sialic acid binding lectin isolated from the American horseshoe crab Limulus polyphemus. Agglutinins that bind to sialic acid are also found in the Orthomyxoviridae viral family, which includes influenza viruses, Papoviridae, Reoviridae, and Adenoviridae (Weis et al. 1988).

3.4 Classification Based on Source (Plants, Animal, Microbes)

3.4.1 Plant Lectins

Plants contain lectins that bind specifically to mono- or oligosaccharides with particular properties. These carbohydrate-binding plant proteins, also known as lectins, agglutinins, or haemagglutinins, are a large collection of proteins with diverse applications. Approximately 500 distinct plant lectins have been identified and described in some detail, according to recent research analysis (Van Damme et al. 1998). All these lectins exhibit significant applications on the basis of their specific carbohydrate-binding through carbohydrate recognition domain. Plant lectins are classified into merolectins, hololectins, chimerolectins, and superlectins (Table 3.2) based on their carbohydrate recognition domain (Fig 3.1). Merolectins are proteins that are made up entirely of a single carbohydrate-binding domain, e.g., small chitin-binding lectins. Merolectins are monovalent by definition and so cannot precipitate glycoconjugates or cause agglutination of cells.

Hololectins are made up entirely of carbohydrate into a special category called superlectins. They are made up of at least two carbohydrate-binding domains that are not identical or comparable, but recognize structure binding domains, although at least two of them are identical or highly similar. Hololectins can agglutinate because they are divalent or multivalent (Damme et al. 1998).

Plant lectins are also classified into families based on some shared features as legume lectins, type II ribosome-inactivating proteins, monocot mannose-binding lectins, and other lectins (Lam and Ng 2011). The most well-known kind of lectin is legume lectin. Leguminous plants' seeds have a greater lectin content than their bark, leaves, roots, and stems. The lectins of the Gramineae (cereals, such as wheat germ)

Table 3.2 Plant lectins classification

Carbohydrate-binding site	Structure and evolution	Ligand specificity
1. Merolectins	1. Amaranthin	1. Glucose
2. Hololectins	2. Chitin-binding lectin	2. Galactose
3. Chimera lectins	3. Cucurbitaceae lectin	3. N-acetyl D-glucosamine
4. Superolectins	4. Jacalin	4. Fucose
	5. Legume lectin	5. Sialic acid
	6. Mannose-binding lectin	6. N-acetyl D-galactosamine
	7. Type 2 ribose inactivating lectin	

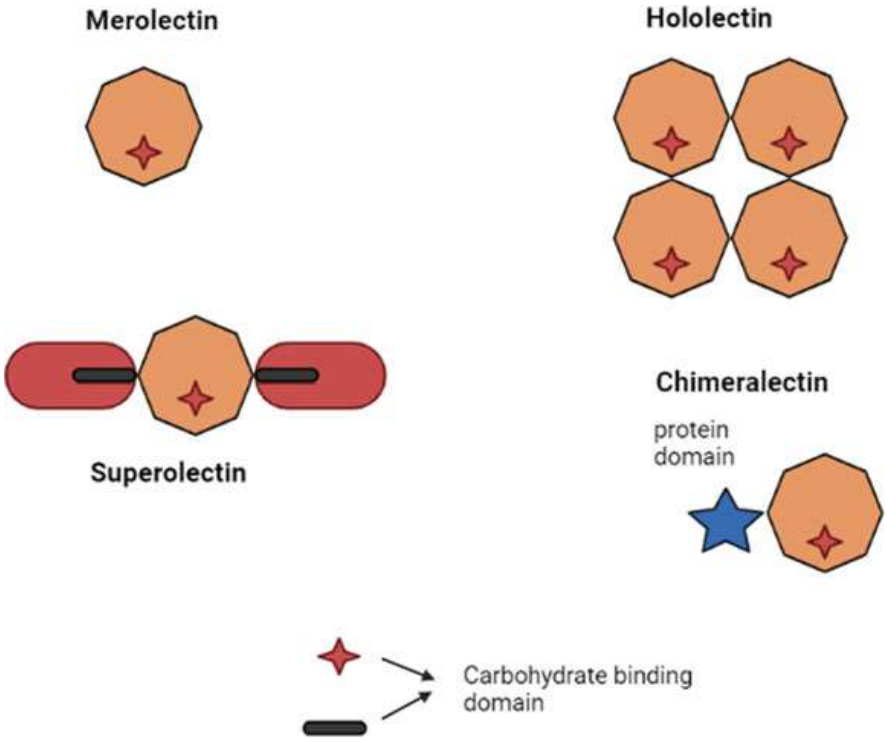


Fig. 3.1 Classification of plant lectins based on carbohydrate-binding domain. (Created with biorender.com)

and Solanaceae plant families have also been discovered (potatoes and tomatoes). Monocot-binding lectins are made up of 1, 2, 3, or 4 12 kDa subunits with a specific affinity for mannose, whereas chitin-binding lectins are built up of hevein domains (Damme et al. 1998). Type 2 ribosome-inactivating proteins are chimerolectins composed of a polynucleotide: adenosine glycosidase domain (also known as the A chain) and a carbohydrate-binding domain positioned in parallel (the so-called B chain). Both chains are produced on the same precursor molecule, which is subsequently processed post-translationally by eliminating a linker between the A and B chains (Barbieri et al. 1993). Major plant lectins include concanavalin A, wheat germ agglutinin, soybean agglutinin, Limba bean, wax bean agglutinin, and Red bean agglutinin.

3.4.2 Animal Lectins

The first animal lectin discovered was the asialoglycoprotein receptor in mammalian cells, which was useful in determining how animal lectins differ in glycoconjugate binding. Depending on their cellular location and the binding specificities of their carbohydrate recognition domain (CRD) modules, animal lectins are divided into numerous groups (Fig 3.2). Animal lectins were formerly divided into two structural

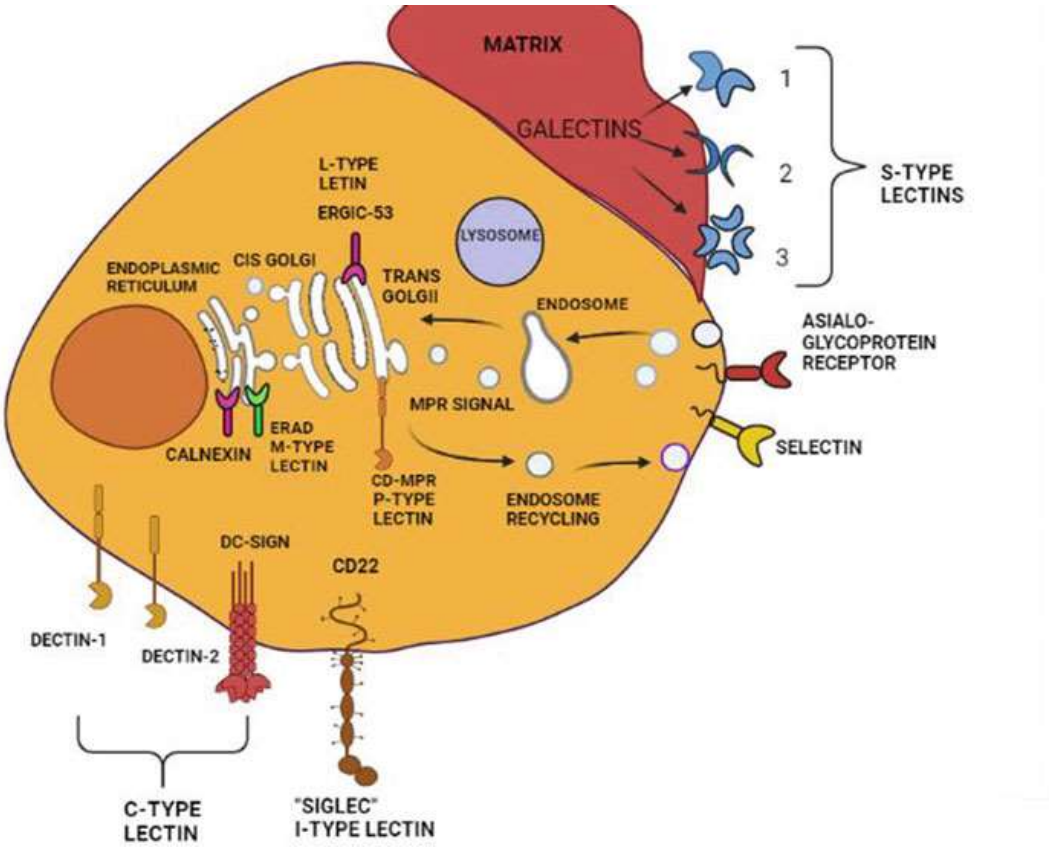


Fig. 3.2 Different types of animal lectins and their cellular location (Created with biorender.com)

families: C-type (Ca^{2+} dependent binding) and S-type-galectins (sulfhydryl dependent binding) (Drickamer 1988). The most important animal lectins, such as endocytic receptors, mannose receptors, selectins, and collectins, belong to the C-type lectin family.

Recent research has identified more than 100 animal lectins and classified them into different families based on the complexity of carbohydrate ligands, metabolic processes they perform, expression levels, and their reliance on divalent cations. These families include calnexin, F-lectin, intelectin, chitinase like lectin, F-box lectin (Table 3.3), and others (Cummings and McEver 2009). C-type lectins are Ca^{2+}-dependent lectins that are found in the extracellular matrix, serum, and membrane and have a conservative domain known as the carbohydrate recognition domain. The distinctive feature of the carbohydrate recognition domain is the direct interaction of Ca^{2+} with the bound sugar via coordination bonds (CRD) (Drickamer 1993).

C-type lectin includes endocytic receptors such as asialoglycoprotein receptors, macrophage mannose receptors, natural killer cell receptors, kupffer cell receptors along with other molecules such as collectin and selectin (cell adhesion molecules) (Cummings and McEver 2009). Another type of animal lectin is S-type lectins that are soluble β-galactosidase binding lectins which bind glycoconjugate through a

Table 3.3 Classification of animal lectins and their ligands

Lectin family	Ligand	References
C-lectin – Asialoglycoprotein receptor – Macrophage mannose Receptor – Natural killer cell receptor – Kupffer cell receptor – Selectins – Collectins	Gal, GalNac, mannose, heparin, fucose glycan, GalNAc, β-Fuc-containing glycans, fucose, sialic acid, sulfated glycans, Man, Fuc, GlcNAc	Cummings and McEver (2009)
S-lectin/galectin	β-Galactosidase	Wada and Kanwar (1997)
M-lectin	Mannose	Tong and Kornfeld (1989)
P-lectin	M6P	Gupta (2012b)
L-lectin	Various	Etzler et al. (2009)
I-lectin	Sialic acid	Bertok et al. (2013)
R-lectin	Diverse lectins	Gupta and Gupta (2012)
Other class of lectins Calnexin F-box lectin Intelectin F-lectin Chitinase like lectin	Glc Man9, Glc Nac2, Gal, Galactofuranose, pentoses, fucose ending glycans, chito-oligosaccharides	Matsuo et al. (2003), Gupta (2012c), Khalil (2015), Vasta et al. (2012), Fusetti et al. (2002)

Ca^{2+} independent manner. It functions based on the conservation of a group of amino acid residues that resemble the characteristics of carbohydrate-binding domain (CRD) (Barondes et al. 1994). L-type lectins are proteins discovered first in the seeds of leguminous plants. For example, ERGL has been identified, where it lacks some basic residues for glycan-binding but, like ERGIC, plays an important role in the secretion of various glycoproteins in specific tissues (Yerushalmi et al. 2001). The term "P-type" lectin family denotes the binding affinity of carbohydrate recognition domain (CRD) in these proteins towards mannose 6-phosphate (M6P). MPRs play a major role in targeting the lysosomal enzymes (Dahms 2002). Other significant lectins include calnexin, calreticulin, calmegin, and calreticulin 2 that serves as the prototype for a small group of ER-resident chaperone proteins (Thomsen et al. 2011), F-box lectins have been identified in the murine F-box protein Fbs1, which functions similarly to the carbohydrate recognition domain (CRD) (Yoshida et al. 2003), and Ficolins which are soluble oligomeric proteins composed of trimeric collagen-like domains that stimulate the complement system (Thomsen et al. 2011).

3.4.3 Microbial Lectins

Lectins derived from fungus, bacteria, protozoa, and viruses make up microbial lectins. Since the 1970s, only a few lectins have been identified nevertheless, the

relevance of microbial lectins has been recognized as a result of ongoing study in this subject, which has led to substantial investigations on lectins from microbes (Slifkin and Doyle 1990). Alfred Gottschalk was the first to discover a microbial lectin in the early 1950s. The influenza virus was used to isolate this lectin, which was shown to be of viral origin. In the 1970s, Sharon et al. were the first to investigate bacterial lectins (Wiederschain 2009). The major function of microbial lectins is to bind to host cells, which is required for infection to occur. Microbes benefit from lectins because they help them attach to the cell surface. Such interactions that aid in microbial growth must be critically analyzed to essentially prevent pathogenic infections and diseases in humans (Ofek and Doyle 1994b). Major microbial lectins include haemagglutinin, adhesins, and bacterial toxins. The influenza virus haemagglutinin, which binds to sialic acid–containing glycans, is a significant viral glycan-binding protein. The specificity of this interaction, like that of other glycan-binding proteins with their glycosyl ligands, is modest, because the haemagglutinin oligomerizes into trimers and the host cell has a large density of glycan receptors, the sensitivity for cell membranes rises (Rott et al. 1996). Bacterial lectins are mostly of fimbriae (hairs) or pili (threads), which are elongated, submicroscopic protein structures that bind with glycoconjugate receptors on the host cells. The mannose-specific fimbriae, the galactose-specific fimbriae, and the N-acetyl galactose-specific fimbriae are identified to be effective cell adhesion molecules (Ofek and Doyle 1994b). Other forms of microbial lectins include bacterial toxins. Bacteria produce lectins termed toxins to prevent other bacteria from colonizing, allowing them to gain an advantage in the struggle for resources and space. For example, A lectin called bacteriocin with two b-lectin domains produced by a gram-negative bacteria proteobacteria was reported to eliminate other bacteria through contact dependent inhibition (Ghequire et al. 2018). A variety of parasites, in addition to viruses and bacteria, employ glycans as adhesion receptors. *Entamoeba histolytica* produces a heterodimeric lectin that specifically binds to galactose/N-acetylgalactosamine residues on the host cell (Wiederschain 2009).

3.5 Conclusion

Carbohydrates are found on the surface of all living cells as a component of glycoconjugates and are involved in diverse physiological functions such as cellular communication, antimicrobial activity, mitogenesis, tumor biomarkers, therapeutic strategies, etc. Such characteristics of lectins make it an inquisitive area for researchers to analyze more lectins of natural origin with beneficial effects. Such inventions of lectins could be significant only if it is classified according to their characteristics such that they could be easily accessed for further analysis. As mentioned above lectins could be classified in several ways according to their source, glycoconjugate specificity, and binding patterns. Further recent research also focuses on the classification of lectins on the basis of evolutionary relationship and gene analysis using bioinformatics tools. One such report is the utilization of

Glyco Bioinformatics databases and tools that aid in classifying lectins upon their functional differences and versatility in addition to origin and specificity. For example, Unilectin3D, a portal dedicated to lectin 3D structures and lectin/glycan complexes was launched in 2018, with 1740 structures encompassing 428 distinct lectins and 765 references. UniLectin3D has been validated as the primary source of data on lectin 3D structures and their glycoconjugate interaction (Bonnardel et al. 2021).

Acknowledgments We are grateful for the kind support from PG Research & Department of Biotechnology, National College, Tiruchirappalli 620001, Tamil Nadu, India. Kiyun Park, Fisheries Research Institute, Chonnam National University, Yeosu, South Korea, Ihn-Sil Kwak, Fisheries Research Institute, Chonnam National University, Yeosu, South Korea.

Conflict of Interest The authors have no conflicts of interest to declare.

References

de Azevedo MR, Ainouz IL (1981) Lectins from seeds of jack fruit (Artocarpus integrifolia L.): isolation and purification of two isolectins from the albumin fraction. Biol Plant 23:186–192

Barbieri L, Battelli MG, Stirpe F (1993) Ribosome-inactivating proteins from plants. Biochim Biophys Acta 1154:237–282

Barondes SH, Cooper DN, Gitt MA, Leffler H (1994) Galectins. Structure and function of a large family of animal lectins. J Biol Chem 269:20807–20810. https://doi.org/10.1016/S0021-9258(17)31891-4

Barre A, Bourne Y, Van Damme EJ et al (2001) Mannose-binding plant lectins: different structural scaffolds for a common sugar-recognition process. Biochimie 83:645–651

Barre A, Bourne Y, Van Damme EJM, Rougé P (2019) Overview of the structure¯function relationships of Mannose-specific lectins from plants, algae and fungi. Int J Mol Sci 20:254

Bertok T, Gemeiner P, Mikula M et al (2013) Ultrasensitive impedimetric lectin based biosensor for glycoproteins containing sialic acid. Mikrochim Acta 180:151–159

Bonnardel F, Mariethoz J, Pérez S et al (2021) LectomeXplore, an update of UniLectin for the discovery of carbohydrate-binding proteins based on a new lectin classification. Nucleic Acids Res 49:D1548–D1554

Chervenak MC, Toone EJ (1995) Calorimetric analysis of the binding of lectins with overlapping carbohydrate-binding ligand specificities. Biochemistry 34:5685–5695

Chesterton CJ (1987) Microbial lectins and agglutinins: properties and biological activity: edited by David Mirelman John Wiley & Sons; New York, 1986 xv+ 443 pages.£ 59.35. FEBS Lett 226:202–203

Chetty R, Cooper K, Gown A (2016) Ulex europaeus agglutinin 1 lectin (UEA-1). In: Leong's manual of diagnostic antibodies for immunohistology. Cambridge University Press, Cambridge, pp 467–468

Cordain L (1999) Cereal grains: humanity's double-edged sword. World Rev Nutr Diet 84:19–73

Crocker PR (2002) Genomic analysis of novel Siglecs (sialic acid binding Ig-type lectins). Biochem Soc Trans 30:A3–A3

Crocker PR, Varki A (2001) Siglecs, sialic acids and innate immunity. Trends Immunol 22:337–342

Cummings RD, McEver RP (2009) C-type lectins. In: Essentials of glycobiology. Cold Spring Harbor Laboratory Press, Cold Spring Harbor, NY

Dahms N (2002) P-type lectins. Biochim Biophys Acta 1572:317–340
Damme EJMV, Peumans WJ, Barre A, Rougé P (1998) Plant lectins: a composite of several distinct families of structurally and evolutionary related proteins with diverse biological roles. Crit Rev Plant Sci 17:575–692
Drickamer K (1988) Two distinct classes of carbohydrate-recognition domains in animal lectins. J Biol Chem 263:9557–9560
Drickamer K (1993) Evolution of Ca^{2+}-dependent animal lectins. Prog Nucleic Acid Res Mol Biol 45:207–232
Drickamer K, Fadden AJ (2002) Genomic analysis of C-type lectins. Biochem Soc Symp 69:59–72
Drickamer K, Taylor ME (2015) Recent insights into structures and functions of C-type lectins in the immune system. Curr Opin Struct Biol 34:26–34
Drickamer K, Dordal MS, Reynolds L (1986) Mannose-binding proteins isolated from rat liver contain carbohydrate-recognition domains linked to collagenous tails. Complete primary structures and homology with pulmonary surfactant apoprotein. J Biol Chem 261:6878–6887
Etzler ME, Surolia A, Cummings RD (2009) L-type lectins. In: Varki A, Cummings RD, Esko JD et al (eds) Essentials of glycobiology, 2nd edn. Cold Spring Harbor Laboratory Press, Cold Spring Harbor, NY
Fusetti F, von Moeller H, Houston D et al (2002) Structure of human chitotriosidase. Implications for specific inhibitor design and function of mammalian chitinase-like lectins. J Biol Chem 277: 25537–25544
Ghequire MGK, Swings T, Michiels J et al (2018) Hitting with a BAM: selective killing by lectin-like bacteriocins. MBio 9:e02138-17
Goldstein IJ, Hayes CE (1978) The lectins: carbohydrate-binding proteins of plants and animals. Adv Carbohydr Chem Biochem 35:127–340
Goldstein IJ, Winter HC, Poretz RD (1997) Plant lectins: tools for the study of complex carbohydrates. In: Glycoproteins II. Elsevier, Amsterdam, pp 403–474
Gupta GS (2012a) Pentraxins: the L-type lectins and the C-reactive protein as a cardiovascular risk. In: Animal lectins: form, function and clinical applications. Springer Vienna, Vienna, pp 163–188
Gupta GS (2012b) Mannose-6-phosphate receptor homologous protein family. In: Animal lectins: form, function and clinical applications. Springer Vienna, Vienna, pp 109–122
Gupta GS (2012c) Lectins of ERAD pathway: F-box proteins and M-type lectins. In: Animal lectins: form, function and clinical applications. Springer Vienna, Vienna, pp 123–141
Gupta RK, Gupta GS (2012) R-type lectin families. In: Animal lectins: form, function and clinical applications. Springer Vienna, Vienna, pp 313–330
Hamid R, Masood A, Wani IH, Rafiq S (2013) Lectins: proteins with diverse applications. J Appl Pharm Sci 3:S93–S103
Hardman KD, Ainsworth CF (1972) Structure of concanavalin A at 2.4-Ang resolution. Biochemistry 11:4910–4919
Helliwell TR (1998) Applications of lectin histochemistry and cytochemistry in diagnosis and prognosis. Methods Mol Med 9:73–94. https://doi.org/10.1385/0-89603-396-1:73
Hirabayashi J (1996) Application of site-directed mutagenesis to structure–function studies of carbohydrate-binding proteins. In: Gabius H-J, Gabius S (eds) Glycosciences. Wiley-VCH Verlag GmbH, Weinheim, pp 355–368
Hirabayashi J, Kasai K (1993) The family of metazoan metal-independent beta-galactoside-binding lectins: structure, function and molecular evolution. Glycobiology 3:297–304
Hudgin RL, Pricer WE, Ashwell G et al (1974) The isolation and properties of a rabbit liver binding protein specific for asialoglycoproteins. J Biol Chem 249:5536–5543
Khalil A (2015) Studies on the binding specificity of intelectin. University of Alberta Libraries, Edmonton
Kolatkar AR, Weis WI (1996) Structural basis of galactose recognition by C-type animal lectins. J Biol Chem 271:6679–6685

Lam SK, Ng TB (2011) Lectins: production and practical applications. Appl Microbiol Biotechnol 89:45–55

Landsteiner K, Raubitschek H (1907) Observations on hemolysis and hemagglutination. C Bakt 45: 660

Levy NJ (1979) Wheat germ agglutinin blockage of chlamydial attachment sites: antagonism by N-acetyl-D-glucosamine. Infect Immun 25:946–953

Lis H, Sharon N (1998) Lectins: carbohydrate-specific proteins that mediate cellular recognition. Chem Rev 98:637–674

Ma YJ, Garred P (2018) Pentraxins in complement activation and regulation. Front Immunol 9: 3046

Macholz R (1988) The lectins. Properties, functions, and applications in biology and medicine. Herausgegeben von I. E. Liener, N. Sharon und I. J. Goldstein. 600 Seiten, zahlr. Abb. und Tab. Academic Press, Inc., Orlando u. a. 1986. Preis: 54,—£; 72,50 $. Nahrung 32:212–213

Matsuo I, Wada M, Manabe S et al (2003) Synthesis of monoglucosylated high-mannose-type dodecasaccharide, a putative ligand for molecular chaperone, calnexin, and calreticulin. J Am Chem Soc 125:3402–3403

Munro S (2001) The MRH domain suggests a shared ancestry for the mannose 6-phosphate receptors and other N-glycan-recognising proteins. Curr Biol 11:R499–R501

Nio-Kobayashi J (2017) Tissue- and cell-specific localization of galectins, β-galactose-binding animal lectins, and their potential functions in health and disease. Anat Sci Int 92:25–36

Nizet V, Varki A, Aebi M (2015) Microbial lectins: hemagglutinins, adhesins, and toxins. In: Varki A, Cummings RD, Esko JD et al (eds) Essentials of glycobiology, 3r edn. Cold Spring Harbor Laboratory Press, Cold Spring Harbor, NY

Nsimba-Lubaki M, Peumans WJ, Carlier AR (1983) Isolation and partial characterization of a lectin from Euphorbia heterophylla seeds. Biochem J 215:141–145

Ofek I, Doyle RJ (1994a) Bacterial adhesion to cells and tissues. Springer US, Boston, MA

Ofek I, Doyle RJ (1994b) Principles of bacterial adhesion. In: Bacterial adhesion to cells and tissues. Springer US, Boston, MA, pp 1–15

Peumans WJ, Van Damme JM, Barre A, Rougé P (2001) Classification of plant lectins in families of structurally and evolutionary related proteins. Mol Immunol Complex Carbohydr 2:27–54

Powell LD, Varki A (1995) I-type lectins. J Biol Chem 270:14243–14246

Quiroga AV, Barrio DA, Añón MC (2015) Amaranth lectin presents potential antitumor properties. LWT Food Sci Technol 60:478–485

Ramkumar TP, Hammache D, Stahl PD (2002) The macrophage mannose receptor and innate immunity. In: Innate immunity. Humana Press, Totowa, pp 191–204

Rinderle SJ, Goldstein IJ, Matta KL, Ratcliffe RM (1989) Isolation and characterization of amaranthin, a lectin present in the seeds of Amaranthus caudatus, that recognizes the T-(or cryptic T)-antigen. J Biol Chem 264:16123–16131

Rini JM (1995) Lectin structure. Annu Rev Biophys Biomol Struct 24:551–577

Rivkin E, Tres LL, Kaplan-Kraicer R et al (2000) Molecular cloning of rat sperm galactosyl receptor, a C-type lectin with in vitro egg binding activity. Mol Reprod Dev 56:401–411

Rosen SD, Bertozzi CR (1994) The selectins and their ligands. Curr Opin Cell Biol 6:663–673

Rott O, Charreire J, Cash E (1996) Influenza A virus hemagglutinin is a B cell-superstimulatory lectin. Med Microbiol Immunol 184:185–193

Ryva B, Zhang K, Asthana A et al (2019) Wheat germ agglutinin as a potential therapeutic agent for leukemia. Front Oncol 9:100

Sankaranarayanan R, Sekar K, Banerjee R et al (1996) A novel mode of carbohydrate recognition in jacalin, a Moraceae plant lectin with a beta-prism fold. Nat Struct Biol 3:596–603

Schauer R (1983) Sialic acids as potential determinants on differentiation antigens. Biochem Soc Trans 11:270–271

Shah KU, Rocca JG (2004) Lectins as next generation mucoadhesives for specific targeting of the gastrointestinal tract. Drug Deliv Technol 4:1

Sharon N, Lis H (2004) History of lectins: from hemagglutinins to biological recognition molecules. Glycobiology 14:53R–62R
Sharon N, Lis H (2007) Lectins. Springer, Dordrecht
Sharon N, Lis H (2013) Lectins. In: Encyclopedia of biological chemistry. Elsevier, Amsterdam, pp 701–705
Shaw L, Yousefi S, Dennis JW, Schauer R (1991) CMP-N-acetylneuraminic acid hydroxylase activity determines the wheat germ agglutinin-binding phenotype in two mutants of the lymphoma cell line MDAY-D2. Glycoconj J 8:434–441
Skea DL, Christopoulous P, Plaut AG, Underdown BJ (1988) Studies on the specificity of the IgA-binding lectin, jacalin. Mol Immunol 25:1–6
Slifkin M, Doyle RJ (1990) Lectins and their application to clinical microbiology. Clin Microbiol Rev 3:197–218
Stahl PD (1990) The macrophage mannose receptor: current status. Am J Respir Cell Mol Biol 2: 317–318
Stehle T, Harrison SC (1997) High-resolution structure of a polyomavirus VP1-oligosaccharide complex: implications for assembly and receptor binding. EMBO J 16:5139–5148
Thomsen T, Schlosser A, Holmskov U, Sorensen GL (2011) Ficolins and FIBCD1: soluble and membrane bound pattern recognition molecules with acetyl group selectivity. Mol Immunol 48: 369–381
Ting SRS, Chen G, Stenzel MH (2010) Synthesis of glycopolymers and their multivalent recognitions with lectins. Polym Chem 1:1392
Tong PY, Kornfeld S (1989) Ligand interactions of the cation-dependent mannose 6-phosphate receptor. Comparison with the cation-independent mannose 6-phosphate receptor. J Biol Chem 264:7970–7975
Transue TR, Smith AK, Mo H et al (1997) Structure of benzyl T-antigen disaccharide bound to Amaranthus caudatus agglutinin. Nat Struct Biol 4:779–783
Tsaneva M, Van Damme EJM (2020) 130 years of plant lectin research. Glycoconj J 37:533–551
Van Damme Els JM, PeumansWJ PA, Bardocz S (1998) Handbook of plant lectins: properties and biomedical applications, 1st edn. Wiley, Chichester
Varki A (2009) Multiple changes in sialic acid biology during human evolution. Glycoconj J 26: 231–245
Vasta GR, Ahmed H, Bianchet MA et al (2012) Diversity in recognition of glycans by F-type lectins and galectins: molecular, structural, and biophysical aspects. Ann N Y Acad Sci 1253:E14–E26
Vasta GR, Amzel LM, Bianchet MA et al (2017) F-type lectins: a highly diversified family of Fucose-binding proteins with a unique sequence motif and structural fold, involved in self/non-self-recognition. Front Immunol 8:1648
Wada J, Kanwar YS (1997) Identification and characterization of galectin-9, a novel beta-galactoside-binding mammalian lectin. J Biol Chem 272:6078–6086
Walujono K, Scholma RA, Beintema JJ, Anton M, Hahn AM (1975) Amino acid sequence of Hevein [of latex]. In: International Rubber Conference, Kuala Lumpur (Malaysia), 20 Oct 1975
Weis W, Brown JH, Cusack S et al (1988) Structure of the influenza virus haemagglutinin complexed with its receptor, sialic acid. Nature 333:426–431
Weis WI, Taylor ME, Drickamer K (1998) The C-type lectin superfamily in the immune system. Immunol Rev 163:19–34
Wiederschain GY (2009) Essentials of glycobiology. Biochemistry (Moscow) 74:1056–1056
Wiley DC, Skehel JJ (1987) The structure and function of the hemagglutinin membrane glycoprotein of influenza virus. Annu Rev Biochem 56:365–394
Wu J, Xie X, Liu Y et al (2012) Identification and confirmation of differentially expressed fucosylated glycoproteins in the serum of ovarian cancer patients using a lectin array and LC-MS/MS. J Proteome Res 11:4541–4552
Yerushalmi N, Keppler-Hafkemeyer A, Vasmatzis G et al (2001) ERGL, a novel gene related to ERGIC-53 that is highly expressed in normal and neoplastic prostate and several other tissues. Gene 265:55–60

Yoshida Y, Tokunaga F, Chiba T et al (2003) Fbs2 is a new member of the E3 ubiquitin ligase family that recognizes sugar chains. J Biol Chem 278:43877–43884

Yosizawa Z, Miki T (1963) Serologically responsible structure of N-acetyl-D-galactosamine for blood .. group A activity. Proc Jpn Acad 39:187–192

Young NM, Oomen RP (1992) Analysis of sequence variation among legume lectins. A ring of hypervariable residues forms the perimeter of the carbohydrate-binding site. J Mol Biol 228: 924–934

Zeng Q, Lin F, Zeng L et al (2019) Purification and characterization of a novel immunomodulatory lectin from Artocarpus hypargyreus Hance. Int Immunopharmacol 71:285–294

Zhang T, Miller MC, Zheng Y et al (2017) Macromolecular assemblies of complex polysaccharides with galectin-3 and their synergistic effects on function. Biochem J 474:3849–3868

ResearchGate

See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/351797930

Functional genomics approaches for combating the effect of abiotic stresses

Chapter · January 2021

DOI: 10.1016/B978-0-12-822849-4.00013-9

CITATION
1

READS
138

5 authors, including:



Alkesh Hada
Indian Agricultural Research Institute
51 PUBLICATIONS **245** CITATIONS
SEE PROFILE



Mohamed Jaabir
National College, Tiruchirappali
22 PUBLICATIONS **176** CITATIONS
SEE PROFILE



Nisha Singh
Gujarat Biotechnology University
62 PUBLICATIONS **906** CITATIONS
SEE PROFILE

Chunoti Changwal
Indian Agricultural Research Institute
6 PUBLICATIONS **18** CITATIONS
SEE PROFILE

Some of the authors of this publication are also working on these related projects:

Project Mango Genome View project

Project Q2V: DBT View project

All content following this page was uploaded by Anil Kumar on 05 July 2021.

The user has requested enhancement of the downloaded file.

Chapter 8

Functional genomics approaches for combating the effect of abiotic stresses

Alkesh Hada[1], M.S. Mohamed Jaabir[1], Nisha Singh[2], Chunoti Changwal[3] and Anil Kumar[4,*]

[1]*Department of Biotechnology & Microbiology, National College (Autonomous), Tiruchirappalli, India,* [2]*Institute of Genomic Diversity, Cornell University, Ithaca, NY, United States,* [3]*Plant Physiology, ICAR-Indian Agricultural Research Institute, New Delhi, India,* [4]*Department of Entomology, Nematology and Chemistry Units, Agricultural Research Organization (ARO), The Volcani Center, Rishon LeZion, Israel*

**Corresponding author. Email: anilmalik58@gmail.com*

8.1 Introduction

Abiotic stressors/factors, for instance, extremes temperature, drought, cold, salinity and sodicity, heavy-metal toxicity, and waterlogging, among others, are the major crop yield−limiting factors in agriculture worldwide (Canter, 2018; Zörb et al., 2019). In the last 25−30 years, about 37% salinity in the irrigated lands has increased, and the global average temperature has also shown to be increased up to 4.9°C by the year 2100 (Raftery et al., 2017). The abovementioned stresses are prone to affect about 90% of arable lands that lead to reducing crop yields up to 50%−70% in both natural and agricultural systems, which is a serious consequence for the economy and food security (Akpınar et al., 2013).

The continuous manifestations of cold or chilling temperature and heat stress during different developmental stages of any crop plants have high impacts on developmental cascades of any plants, leading to reduction in optimal biochemical and physiological functioning (Zhou et al., 2018; Takahashi and Shinozaki, 2019). Cold stress has a strong negative impact on grain filling that leads to poor grain yield and qualities (Dreccer et al., 2018).

Rapid climatic abnormalities and global warming have resulted in increased evaporation and decreased precipitation, making more frequent drought spells globally (Kogan et al., 2019). It strongly influences the growth of plants and reduced crop yield (Bartlett et al., 2019). Drought impacts crop plants in diverse ways, including alterations in growth patterns, plant physiology, genotypes, developmental stages, durations, and defense mechanisms (Zandalinas et al., 2018) (Fig. 8.1).

Saline stress or salinity is becoming the most important abiotic stress that impacts the global food production, as about more than 45 million ha of irrigated land are under salinity stress all over the world, and it is expected that more than 50% of arable land may possibly be saline affected by the year 2050 (Munns and Tester, 2008). The majority of lands affected by saline stress is situated in semiarid or arid regions (Huang et al., 2019). Generally, salinity stress damages biomolecules (e.g., nucleic acids, proteins, and lipids) by reactive oxygen species (ROS) generation (Kundu et al., 2018). Recently, Isayenkov and Maathuis (2019) suggested that the heavy roots system is crucial in improving salt-stress tolerance to increase crop yield.

Plant's growth and development mainly depend on nutrients that they acquire from the soil system. But the continuous increase in mineral/metal toxicity in arable lands is one of the severe risks of environmental sustainability and agricultural systems (Proshad et al., 2018). The excessive utilization of synthetic chemical fertilizers/nutrients leads to agricultural lands with toxic metals contamination and causes the acquisition of these heavy metals inside plants, resulting in reduced grain filling and increased threat to human and animal health. For example, cadmium (Cd) contamination in the soil leads to reduced growth of plants, as evident from stunting in plants, reduction in the size of the leaf, and reduction in yield of shoots and roots dry matter (Shah et al., 2019). Arsenic (As), one of the most important metal element present globally, causes loss of functions in plant cells (Ghosh and Mukhopadhyay, 2019).

For survival in adverse environmental stresses, plants generally produced the compatible osmolytes compounds, such as glycine betaines, prolines, amines, and soluble sugars, to support the stressed plants by balancing the osmotic pressure; maintaining the integrity of cell membranes, protein stability, and ROS detoxification; and regulating cell

Stress Tolerance in Horticultural Crops. DOI: https://doi.org/10.1016/B978-0-12-822849-4.00013-9
© 2021 Elsevier Inc. All rights reserved.

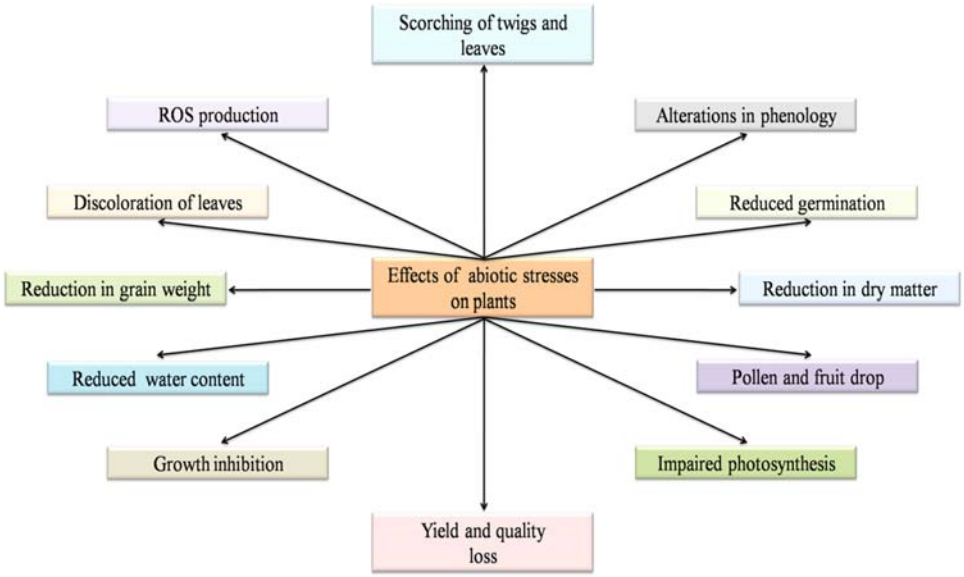


FIGURE 8.1 General effects of abiotic stresses on horticultural crops. *ROS*, Reactive oxygen species.

volume in stressed plants (Blum, 2017). These natural compounds act as stress-specific sensors and do not affect the normal functioning of crop plants (Takahashi and Shinozaki, 2019).

To feed the entire world in the scenario of the climatic abnormalities, and increasing world population which is going to exceed more than 9 billion by 2050, aggressively competing with the agriculture along with water and land resources (Assefa and Erusulo, 2016). Each year about 44 metric t of food production will be required to meet the food demand, and to feed the global population, stress-tolerant varieties of diverse crops are desired (Lesk et al., 2016). Evolutionary changes can help several plant species to adapt to diverse adverse conditions. In these practices, some species show tolerance to different stresses compared to others, which makes them extensive for the development of local cultivars (Phukan et al., 2016). But to attain this, it is crucial to identify the novel genetic variations for crops to tolerate the expected intensity of stresses beyond those experienced in the natural selection of domesticated crops (Battisti and Naylor, 2009). As traditional practices for stress-tolerance cultivar/varieties identification in crop improvements reaches their limits, the agricultural practice has to implement new approaches to meet the food demands. This is instant for plant genetic breeders to evoke and exploit the lost genetic diversity and germplasms as several wild-type and landrace relatives are prospective sources of stress tolerance. Hence, wild-type and landraces species of various crops, having unknown stress-responsive genes, should be characterized and incorporated into modern cultivars (Mammadov et al., 2012). Identifying the stress-responsive genes and improving abiotic stresses tolerance using these genes become the most important intent in plant genetic breeding programs worldwide.

A suitable breeding approach selection for developing stress-tolerant varieties/cultivars is a primary step in the successful breeding program. Thus approaches that can utilize wild-type and landraces, transfer definite genes, identify and transfer genes unambiguously, and require less time in developing cultivars are of great value. Dissecting the genetic basis of intraspecific variations in traits that shows tolerance to abiotic stress will be valuable in selecting and generating positive variations within species. Still, partial success has been attained through conventional strategies, for instance, inter- or intrageneric hybridizations, induced mutations, and/or somaclonal variations (Bhullar and Gruissem, 2013).

Plants generally adopted various biochemical, physiological, and metabolic approaches to survive against abiotic stresses. But the network of complex signaling pathway prediction in response to diverse abiotic stresses is a great challenge (Chawla et al., 2011). The effort to accommodate multidimensional biological information in networks and model leads to the advancement of system biology. In this direction, success in developing crops tolerance to different stresses has been attained to some extent, resulting in improved crop yield (Mickelbart et al., 2015). Novel approaches are urgently desired to conquer the limitations of traditional practices, for instance, lack of precision and necessity of substantial time to enhance the productivity of crops in the current scenario of climatic fluctuations. The recent availability of genome editing advanced with novel high-throughput tools has led to revolutionizing the crop improvements. The advancement in molecular strategies and bioinformatics tools directly influences the applicability in crop-improvement techniques by translating the whole genomic regions interpreting plant molecular responses (Edwards, 2016). Genome-editing tools offer extensive opportunities to introduce the target modifications in the form of mutation, insertion and/or

deletion, and precise sequence modification in the genome, efficiently in a broad range of organisms. Commonly, transcriptional activator-like effector nucleases (TALENs), zinc finger nucleases (ZFNs) and clustered regularly interspaced short palindromic repeat (CRISPR)-Cas9 (CRISPR-associated nuclease 9) are the most frequently used genome-editing tools. Generally, the sequence-specific nucleases make double-strand breaks (DSBs) in a specific region in the genome, which is repaired by nonhomologous end joining (NHEJ), that leads to introducing the insertion and deletion mutations and/or homology-directed repair, which are used in introducing point mutations and new domains via recombination.

Modern technology advances and the challenges described previously in crop productivity have led to the development of high-throughput tools to explore and utilize plant genomes in agricultural crop improvements. The complex biochemical and molecular regulatory network involved in abiotic stress tolerance can be easily interpreted using different "omics" study (Chawla et al., 2011). The omics technologies directed well-designed experiments aim to decipher the whole genome, inclusive of genic and intergenic regions that provide great deep insight concerning the functionality of the particular gene in addition to their effects on the phenotype in a specified biological context. The key intention of this advancement in "omic" is not only to detect the molecular interaction and its relationship among the signaling cascade but also to process the information that consecutively connects definite signals with particular molecular responses and presents a holistic view of molecules at the cellular, tissues, or organism level. The combination of different omics provides many-dimensional biological information, which is being approached through a comparatively new branch as system biology (Chaudhary et al., 2019).

Prior to omics advance, the genetic approach was named "candidate gene-by-gene" in which identification and characterization of a single gene in diverse regulatory networks find out its point in the signaling cascade and its involvement toward stress tolerance. The understanding of plant responses toward various abiotic stresses is improved by the help of functional genomics strategies, for instance, analysis of expressed sequence tags (ESTs), large-scale parallel analysis of gene expression, and targeted or random mutagenesis (Gong et al., 2005). Development of ESTs from the cDNA libraries of stressed plants and their entire genomic sequences provides a supplementary resource for the identification of genes. Additionally, approaches like promoter trapping, gene complementation, and mutagenesis have led to the discovery of important gene pools and, thus, have implemented important efforts toward the characterization of stress-responsive genes (Hasanuzzaman et al., 2015). Further, functional validation of these genes may facilitate to untangle the stress-tolerance networks as well as used in designing different functional markers (FMs) for marker-assisted breeding. The molecular breeding strategies and novel biotechnological tools with genome-editing systems along with reverse genetic approach can exploit these genes to improve abiotic stress tolerance.

In the postgenomic era, wide exploitation of functional genomics approaches has improved our understanding of the intricate networks that operate in stress tolerance. These approaches, in combination with phenomics, will increase our knowledge toward transcript regulations, gene complementation, protein complex formation, and their evolutionary pathways, controlling stress-tolerance traits. Following the introduction of whole-genome sequencing (WGS) programs, progression in DNA-sequencing technologies acquired breakthroughs in this area and achieved the WGS of different organisms, including protists, fungi, and eukaryotic plants (Armbrust et al., 2004; Galagan et al., 2003; Li et al., 2014; Hirakawa et al., 2014; Varshney et al., 2017). Current and fast-emerging technologies like next-generation sequencing (NGS), genome-wide association (GWA), suppression subtractive hybridization, high-throughput phenomics, chromosome engineering, gene-editing systems, gene silencing mechanisms, and bioinformatic approaches have increased our perceptive toward stress signaling cascades and mechanisms. At transcriptome level, RNA sequencing (RNA-seq) and microarrays can use to explicate the differential expression of RNA transcripts and the discovery of novel genes involved in stress response. In response to different stresses, plants constantly need to adjust their transcriptome profiles, which adds the most important step toward the perceptive and establishment of plant gene−regulatory networks. In addition, miRNAs, quantitative trait loci (QTLs), transcription factors (TFs), hormones, metabolites, and stress-related proteins are key players in stress signaling. These factors control the expressions of genes in response to different stresses. TFs interact with various stress-specific hormones, for instance, abscisic acid (ABA), salicylic acid (SA), and jasmonic acid (JA) in mediating abiotic stress response (Nakashima et al., 2014).

In this context the present chapter provides in-depth information on recent advances in functional genomics approaches for crop improvements against abiotic stresses, though the genomics approaches are extremely intermingled, in terms of methodologies and the outcome.

8.2 Functional genomics: an advanced approach for crop improvement

Various "omics" technologies come up to fulfill our understanding at the time of changing environment, cellular processes, genetic control and its interactions, as well as nutritional conditions. The latest omics technology proved to be useful in our perceptive of species and provides its metabolic modifications, which results in the course of contact with

the atmosphere. Such multidimensional and in-depth analyses need large-scale experiments involving complete genetic, structural, and/or functional components. The genomics era had been started with the progress in automated sequencing techniques and led to the first complete genome sequence of the model plant, *Arabidopsis thaliana*. The advancement of high-throughput "omics" approaches has initiated a booming phase of plant molecular biology techniques for regulating changes in the environment. Presently, genetic engineering techniques that introduce any gene directly are coming up as quick, reliable, and efficient methods for improving stress tolerance in plants as compared to conventional breeding approaches. The role of these approaches is to functionally validate the genes involved in stress signaling to understand their distinctive functions (Teotia et al., 2016).

Additionally, diverse TFs regulating the expression of various stress-responsive proteins are also disclosed (Wang et al., 2016b). Now, it is essential to focus the studies of various abiotic stress tolerances in a unified way on a genome-wide scale to elucidate the complete networks related to abiotic stresses. By using the various omics tools, major advancement has been made for perceiving the interaction as well as intricacy of the stress-adaptive systems and their relevant signaling cascades and pathways (Liu et al., 2014b). Using transcript profiles, the identification of the regulatory regions in chromatin organization and the allocation of *cis*-regulatory elements can be predicted computationally. Understanding the functions of any gene was the major challenge, but the progression in high-throughput functional genomics tools makes it easy and possible to discover the novel genes and their functions. Unraveling any gene functions as well as the interactions amongst genes in the regulatory networks can be exploited to produce improved cultivars/varieties (Akpınar et al., 2013) (Fig. 8.2). Though the functions of numerous genes are still unidentified, their function can be correlated in relation to other identified genes, which presents even superior understanding for the entire signaling cascade.

Further, we can obtain an entire overview at the complex cellular level through transcriptomics (RNA-seq) and proteomics (targeted vs nontargeted proteins) in different physiological processes that can facilitate their functions at gene and protein levels (Cramer et al., 2011). As all genes are not consistently turned on at the same time; hence, the

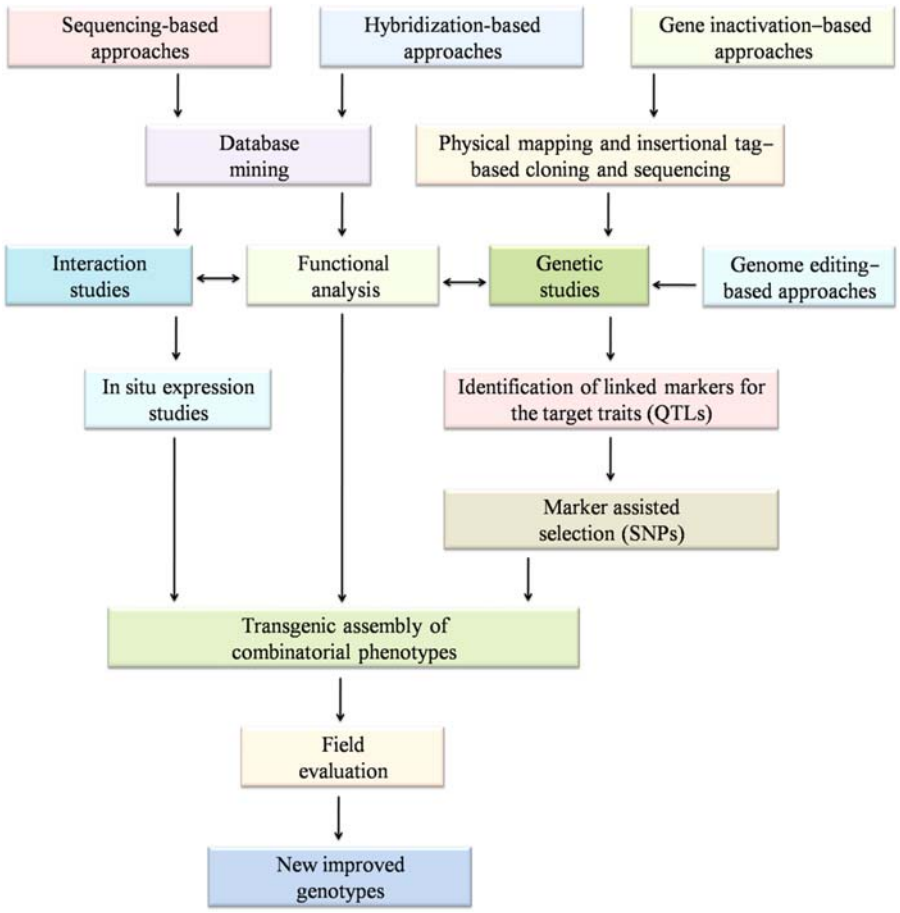


FIGURE 8.2 A systematic flow chart depicting the functional genomics approaches for plant improvements. *SNPs*, Single nucleotide polymorphisms; *QTLs*, quantitative trait loci.

metabolism turns out to be relatively dynamic in the phenotype that cannot be derived from the genotype (Feist and Palsson, 2008). Only understanding the fundamental functions of any gene does not provide insight into its precise role under advert conditions. Therefore the successful integration of the different omics will assist the breeders in selecting the prospective candidates and their best traits to enhance the productivity of crops under different abiotic stresses.

8.2.1 Transcriptome profiling for crops improvement

Despite the widespread information of the mechanisms leading cellular responses to abiotic stresses, our understanding of stress signal insights in the early stages of a stress response is comparatively poor. Transcriptome analyses have presented detailed data of cellular and molecular responses underlying plant adaptation to abiotic stresses (Matsui et al., 2008; Rasheed et al., 2016). Generally, abiotic stresses make some important physiological and molecular changes in plants such as sudden transcriptomic and metabolic changes, osmotic potential changes, decline in leaf turgor pressure, as well as down or cessation in the growth of plants (Tardieu et al., 2018). The plant growth reduction might influence a few tissues more severely than others, for instance, even as the growth of shoots is rigorously inhibited in response to drought, growth of roots may be possible to make an effort to enhance the absorption of water (Sharp et al., 2004). The *A. thaliana* roots under drought stress show a greater diversity of transcriptome profile compared to shoots, revealing numerous new candidate genes that might regulate root responses to stress (Rasheed et al., 2016). Some studies signify that plant tissues that primarily sense or detect the changes in surroundings may experience larger transcriptomic changes compared to the tissues that consequently sense the conditions at the later. Such roots might be affected at an early stage by drought and salts stresses, whereas shoots can detect the heat and cold stresses.

Gene expression of various functional and regulatory as well as cellular and transporter groups that keep the cell membrane's integrity and maintained the ion transport, like protein kinases, phosphatases, osmolytes, aquaporins, late embryogenesis abundant proteins, ROS scavengers, and chaperones, are changed in response to abiotic stresses (Matsui et al., 2008; Rasheed et al., 2016; Kim et al., 2015; Nakaminami et al., 2012; Urano et al., 2010). Likewise, noncoding RNAs, small peptides, and hormones that control the expression of genes and signal transduction act as key players in the mechanisms underlying abiotic stress response (Matsui et al., 2008; Takahashi et al., 2018; Nakaminami et al., 2018).

Novel candidate genes and promoters can be identified using transcriptomic data and used to comprehensively study to know their functional roles under stress conditions (Rasheed et al., 2016; Kim et al., 2017). Additionally, genetic markers can also be identified that would advance the existing tools for marker-assisted breeding. In general, plants possibly will respond in a significantly different way to the same stress at different development stages, such as vegetative versus reproductive stages. Even collected data of the same abiotic stress at different time points might be significantly different, as transcriptional changes are also regulated by diurnal rhythms (Greenham et al., 2017). Transcriptomic data of different developmental stages with different stresses have also been maintained for economically important crops, such as rice, wheat, maize, barley, tomato, potato, strawberry, grapes, poplar, and peanut (Sato et al., 2010; Hawkins et al., 2017). Notably, transcriptome profiling acquired from tissue culture generated plants and plants from the hydroponic medium as well as from soil in response to various stresses is significantly different. Many groups of researchers have monitored the transcriptomic changes in plants under field conditions, though a great attempt is desired to acquire data in response to abiotic stresses at different developmental stages (Sato et al., 2010). This approach can help in the identification of candidate regulatory genes having potentiality to impact stress tolerance under varied environmental situations.

Recent advancements in computational tools signify that even deferent cells in the same tissue might display a special transcriptome profile, highlighting the requisite of single-cell transcriptome analyses. The necessity of single-cell transcriptome analyses is a prerequisite, as every cell has variations owing to the phenomenon that genes are not transcribed continuously but rather undergo short intervals of "on" and "off" states, consequently making transcriptional monitoring difficult (Liu and Trapnell, 2016). Individual cells from the roots and embryos of *A. thaliana* have been profiled that gives a broad view of the transcriptome as well as enlightening the diversity in gene expression amongst cell types over different developmental stages (Shulse et al., 2019). This shows that even with technical difficulties, single-cell analysis possibly will improve the reliability of transcriptome data comparisons between diverse plant species by addressing the distinction present in the tissues or organs (or both) (Libault et al., 2017). In future a better attempt will be required to reveal variations in gene expressions among cells and tissues, especially in response to abiotic stress.

8.2.1.1 Microarray-based approach

In response to different stresses, plants respond and adjust by changing the physiological, biochemical, and metabolic processes, resulting in varying responses of different genes. Transcriptomics is a study of entire sets of RNA transcripts produced by an organism in specific conditions. The most important approach to attain the transcriptomic data over the past two decades has been through chips and microarray technology that still represents an advisable approach based on the ease of data handling and analysis. It provides an essential empirical opportunity to unravel important genetic processes and offer information regarding novel genes conferring tolerance to abiotic stress (Gul et al., 2016). Microarray is a hybridization-based approach in which DNA sequences of an organism are placed on a chip and used as substrates for hybridization for determining the expression of diverse genes in a sample. This offers the relative expression of genes in fold change, after their response toward different stresses (Singh et al., 2015). The array-based techniques are targeted approaches where probes designing needs sequence information (Rahman et al., 2016). Microarray expression and whole genome sequence data of various model species are publically available (www.genevestigator.com/gv/plant.jsp) that offers deeper insights into the intricate gene regulatory networks in diverse stress responses (Urano et al., 2010).

Additionally, functional proteins encoding genes are already identified, and the complex systems of multigene regulation in abiotic stress response are partially interpreted. Low chip-to-chip variation, high reproducibility, plus probe density of Affymetrix Gene Chip are the advantages, but several technical limitations inclusive of cross-hybridization and background noise affect microarray analysis investigating of stress-responsive genes. Though using oligo microarray, numerous plant species have already been analyzed, such as *Arabidopsis* (Richards et al., 2012), soybean (Le et al., 2012), tomato (Martínez-Andújar et al., 2012), corn (Allardyce et al., 2013), rice (Jung and An, 2013), and wheat (Quijano et al., 2015).

8.2.1.2 RNA-sequencing (RNA-seq)

Recently, NGS technologies are contributing extensively to identifying great genomic resources associated with abiotic stress tolerance. RNA-seq analyze transcriptome by sequencing is a cost effective, high-throughput in-depth data analysis tools have the ability to examine the complete genome. RNA-seq is a method of choice that has higher sensitivity and wider applicability as it uses the genomic information to design the probe sets (Klepikova et al., 2016). It does not need gene information and is proficient in identifying unknown transcripts and also offers opportunities to explore noncoding RNAs. The technology offers unprecedented details about transcriptional features as allele-specific expressions, novel-transcribed regions, and a broad potential to capture alternative splicing as well as provides a superior estimate of complete expression levels (Fu et al., 2009). Further, it helps in the understanding of molecular regulations such as mapping of transcription start sites, small RNA characterizations, strand-specific measurements, and RNA editing (Ozsolak and Milos, 2011). Therefore the technique provides precise information and becomes an acceptable choice for different purposes to determine differentially expressed genes. Differential gene expression analyses in response to various abiotic stresses revealed a strong relationship among diverse biochemical pathways inclusive of SA, JA, ABA, and plant defense (Dugas et al., 2011). Of late, RNA-seq analysis was utilized by various groups of researchers to explore the transcriptional changes in diverse crops; for instance, Garg et al. (2016) analyzed different developmental stages of several chickpea genotypes and identified the upregulation of about 4954 genes in drought-tolerant and about 5545 genes in salinity-tolerant genotypes. Similarly, Chopra et al. (2015) found differentially expressed genes in cold-sensitive and cold-tolerant sorghum genotypes using RNA-seq analysis. Likewise, González-Schain et al. (2016) found upregulation of heat shock proteins during anthesis and downregulation of signal transduction plus metabolic pathways-related genes in heat-tolerant cultivars compared to heat-sensitive cultivars of rice.

8.2.1.3 Serial analysis of gene expression (SAGE)

Serial analysis of gene expression (SAGE) is another advanced and alternative tool to facilitate the simultaneous quantitation of thousands of transcripts. In this approach, mRNA be oligo(dT)-trapped, plus reverse transcribed afterward small sequences tags are excerpted to generate long concatenated chain and sequenced, providing an absolute measure of gene expression (Vega-Sánchez et al., 2007). The latest advancements in NGS technologies make SAGE a reliable, sensitive, and high-throughput approach compared to Sanger sequencing (Cheng et al., 2013). With the existence of comprehensive EST databases of different species, SAGE has been widely employed in plants for many years (Breyne and Zabeau, 2001). Moreover, transcription start sites were also identified using SAGE when combined with 5′RACE (rapid amplification of cDNA ends) (Wei et al., 2016). Earlier studies with SAGE revealed new expressed regions and their novel function, including stress responses in the plant genomes (Cheng et al., 2013). Further, several modifications

to the original methodology have been perceived as SuperSAGE and DeepSAGE in which the size of tags is expanded, given that superior efficiency to the annotation (Matsumura et al., 2012).

8.2.1.4 Massively parallel signature sequencing (MPSS)

MPSS is a highly powerful technique of transcription profiling, which allows the parallel studies of millions of transcripts on the genome-wide scale (Akpınar et al., 2013). In this system, tag-based advance is utilized in which PCR products (tagged) acquired from the cDNA are amplified so that each mRNA generates thousands of PCR products having unique tags to ligate to microbeads (Kudapa et al., 2013). Subsequently, extensive ligation-based sequencing needs to perform where a 16−20 bp signature sequence can be identified from each bead, ensuring thousands of signature sequences. MPSS is a high-throughput technique that can identify novel genes efficiently due to longer tags as well as discover novel transcripts predominantly in the species where full genome sequence is not available (Hamilton and Robin Buell, 2012). Small RNA expression and mRNA transcription have also been studied using this technique (Nobuta et al., 2007). MPSS database having expression profiles for numerous important crops like rice, maize, and soybean is available in the public domain (http://mpss.udel.edu/) (Nakano et al., 2006).

8.2.1.5 Expressed sequence tags (ESTs)

One of the major approaches used to examine the expressed gene catalogs of a species is based on ESTs generated from different cDNA libraries expressing transcripts from the different tissues (Rahman et al., 2016). ESTs are partial genic sequences, produced in single-pass sequencing of cDNA clones. Since progression in NGS technology, complete genome or gene-space sequencing database exists for various crops; adding up the transcriptome data provides large numbers of ESTs. These libraries can utilize to identify numerous distinct plus stress-responsive transcripts, but they underrepresent rare transcripts in definite conditions. The primary focus of these EST libraries on functional studies as it offers better approaches for gene identification and genome annotation (Varshney et al., 2006). Several attempts have been made using ESTs sequences to characterize differentially expressed associated genes in higher glycophytes under salinity stress conditions. ESTs libraries of various species of crops have been growing rapidly and maintained as dbEST databases by National Center for Biotechnology Information (NCBI). Still, large-scale cDNA sequencing programs from various species of stress-treated plants and their specific growth stages are necessary to enhance EST datasets. Similarly, the Swissprot tool also offers essential information related to stress-responsive genes amongst plants as well as assigns the putative functions to these genes (Sreenivasulu et al., 2007). Furthermore, gene information and details of gene families having a role in stress responses are able to establish with clustering the ESTs sequences acquired through particular stress-treated cDNA libraries (Li et al., 2014).

8.2.2 Candidate genes and transcription factors

Understanding the molecular mechanisms and stress-responsive gene mining is a major requisite in the improvement of stress-tolerance crops (Khan et al., 2018). Genes involved in stress-tolerance mechanism called candidate genes possibly will involve in the regulation of certain TFs and protein kinases during stresses (Song et al., 2013). TFs are proteins, usually having two main domains, a DNA-binding (DB) domain and the activation domain (AD). The DB domain supports TFs to bind the *cis*-acting element of a promoter region of stress-responsive genes which led the AD close to the target genes, makes activation and/or repression of these genes (Yamasaki et al., 2013). Nearly 10% of genes in the genome of plants essentially encode for TFs (Franco-Zorrilla et al., 2014). TFs activate and/or repress the RNA polymerase activity and may regulate the defined genes; also a single TF possibly will regulate a number of genes that involved in stress tolerance. Due to the involvement of several gene families, the abiotic stress regulatory response in plants becomes complex. It involves the complicated associations between the TFs and *cis*-acting elements. Hence, TFs involved in regulating abiotic stress works independently as well as also coregulates stress responses between each other, pointing to the prospects that tolerance or susceptibility of stresses are regulated by a complicated gene-regulatory networks (Wang et al., 2016b). The complex gene regulatory networks suggest insights associations between TFs and their subsequent target genes (Koryachko et al., 2015)—a computational method termed network component analysis is developed for TF-gene-interaction analysis that facilitates quantitative analysis of TF-gene regulatory networks in *Arabidopsis* floral developments (Ni et al., 2016). The outcome of the method is an analysis of total gene expression in TF-gene regulatory networks of TFs (7) and genes (55).

Some recent studies indicated that the stress-responsive TFs or multiple stress regulatory TF genes could be utilized as a strong candidate for molecular breeding or genetic engineering in the improvement of diverse crop varieties. For

instance, overexpressing the Glycine soja TF (GsNAC019) in *Arabidopsis* and *Pyrus betulifolia* TF (PbeNAC1) showed tolerance to alkaline and cold as well as drought stresses, respectively (Cao et al., 2017; Jin et al., 2017). Similarly, overexpressing bZIP TF (EcbZIP17) of finger millet in transgenic tobacco showed a high germination rate, increased biomass, and survival rate (Ramakrishna et al., 2018). Likewise, overexpression of an MYB TF (MpMYBS3) resulted in improved cold stress tolerance in transgenic banana lines, and MtMYBS from *Medicago truncatula* are improving the primary root growth in transformed *Arabidopsis* and improved salt and drought stress tolerance (Dou et al., 2016; Dong et al., 2017). In the same way, the exogenous expression of *Arabidopsis* AtDREB1A gene conferred higher antioxidant activities as well as photosynthetic rates under drought stress in transgenic *Salvia miltiorrhiza* (Wei et al., 2016). Elsewhere, rice OsWRKY71 belongs to WYKY TF gene family acts as a positive regulator by regulating numerous downstream genes such as WSI76 and OsTGFR in response to cold stress (Kim et al., 2016). The WRKY TFs, SIDRW1, and SLWRKY39 confer tolerance to both biotic and abiotic stress in tomato by activating the pathogenesis-related (PR) and abiotic stress−responsive downstream genes (Liu et al., 2014a; Sun et al., 2015). These findings could be useful in developing better and improved genotypes with tolerance to different abiotic stresses.

8.2.3 QTLs and single nucleotide polymorphisms (SNPs)

Stress tolerance is a quantitative trait encoded by several genes, and, hence, detection of the genomic regions having genes related to stress signaling is necessary. Stress-tolerance crop genotypes and/or varieties development with conventional breeding is laborious and time−consuming, but exactitude breeding using marker-assisted selection (MAS) can expedite the plant breeding programs with high effectiveness (Zafar et al., 2018). Recent developments in NGS technologies make sequencing-based genotyping efficient and worthwhile. The major techniques routinely utilized by researchers are genotyping-by-sequencing, restriction site−associated DNA sequencing, and reduced representation libraries. NGS resequencing is also useful in identification of single nucleotide polymorphisms (SNPs), particularly where the reference genomic sequence is accessible and also for sequence assembly via bacterial artificial chromosomes for the species where reference genome is not available. Especially, NGS also allows additional molecular markers to be developed on a genome-wide scale allowing precision in tracing introgression of definite segments. Hence, molecular markers, in general SNPs, are being used that supplemented extra power to discover genes linked to stresses and aid genome mapping plus germplasms characterization (Akpinar et al., 2017). Compare to other markers, SNPs availability and stability in inheritance offers superior possibilities for studying stress management in numerous ways, for instance, cultivar identification, genetic maps construction, genetic diversity evaluation, genotype versus phenotype association's identification, and MAS (Ganal et al., 2009). SNPs have been discovered in large scale in various crops via different sources of sequences. Recently, several SNPs associated with abiotic stress tolerance have been identified in different crops (Kilasi et al., 2018; Ruggieri et al., 2019). Hence, it is essential to incorporate numerous SNPs associated with different QTLs that aid in stress-tolerance mechanisms.

High-resolution melting technique is a powerful tool in identification of allelic variations. Of late, Garg et al. (2012) found single SNP in heat shock protein sequence (HSP16.9) among heat susceptible and tolerant genotypes that contribute about 29.89% phenotypic variation in grain weight per spike. TFs, such as, *WRKY1*, *DREB1*, $Na+$ transporters, *HKT-1* conferring salt, and drought tolerance, were also mapped by SNPs (Mondini et al., 2012). Similarly, *TaSnRK2.8* gene that plays an important role in ABA signaling, carbohydrate metabolism, and protein−protein interactions was well mapped by SNPs (Zhang et al., 2013). Linkage maps are essential in QTLs mapping as they are created from the genotypic data from multiplexed marker assays (Masoudi et al., 2015). A high-density linkage maps provide the genomic resource for the positional cloning of important genes and are able to apply in comparative genomics to determine chromosomal organization. Traditional QTL mapping involves mapping population development, polymorphic markers identification and genotyping of the mapping populations, genetic maps construction, accurate phenotyping for stress-tolerance traits, and finally, QTL mapping with genotypic and phenotypic data. This process is frequently called linkage analysis−based QTL mapping. Recent advances in genome mapping, functional genomics, and phenomics provide more precise tools for molecular dissection and extensive characterization of the QTLs that regulate the targeted traits known as QTLome.

8.2.4 Genome-wide Association Studies

Association mapping is a promising alternative to conventional linkage mapping to elucidate the genetic basis of complex traits that use the "historical recombination events" from several lineages (Zhao et al., 2011). To understand the specific molecular function of genes is a difficult task for the plant molecular biologist. For this the QTL mapping and

genome-wide association studies (GWAS) approaches offer information on regulatory loci by identifying the chromosomal region(s) associated with particular phenotypes that can be utilized further in identification of the candidate genes. This can decrease the efforts of molecular biology by minimizing the number of genes to be functionally validated. The choice of technique to discover genomic loci is critical. GWAS emerged as a powerful tool that can be applied to any set of germplasms to identify the regulatory loci behind several complex phenotypic traits simultaneously that show variations (Challa and Neelapu, 2018). It offers high mapping resolution and new insights toward the identification of new genes and alleles, especially for multifaceted traits like abiotic stress tolerance in plants (Hall et al., 2010; Lu et al., 2015). Though the linkage mapping based on biparental progenies has been considered valuable to date for discovering some important genes and mapping QTLs, it has several limitations because of restricted allelic diversity as well as genomic resolution (Schuenemann et al., 2011). GWAS offers opportunities to investigate the enormous allelic diversity existing in natural germplasms and have high mapping resolution. QTL regions are quite large and possess hundreds of genes that make it difficult in candidate gene identification; however, the combined approach of QTL and GWAS is effectively utilized to identify candidate genes (Sonah et al., 2015). So far, this approach has been utilizing in numerous plant species, inclusive of sorghum (Chen et al., 2017), *Brassica napus* (Rahaman et al., 2018), rice (Patishtan et al., 2018), wheat (Li et al., 2019), and maize (Gao et al., 2019) to find out the natural variation associated with stresses and to understand its genetic basis. Additionally, the integration of transcriptome profiling with gene expression can offer imperative clues for the discovery of functions of unknown genes (Sonah et al., 2016). Thus combining QTL mapping and GWAS with transcriptome profiling will complement in the identification of differentially expressed candidate genes (Guo et al., 2019).

8.3 Genome editing and reverse genetics based approach

Genome-editing techniques applied in the analysis of gene function and its manipulations are the most recent technologies in functional genomics. Currently, available approaches for genome editing offer exciting possibilities for gene knockouts, target mutations, epigenetic changes, INDEL and sequence modifications, and activation and/or repression of any gene for the improvement of abiotic stress tolerance in plants (Kamburova et al., 2017). The successful targeting of genes in plants is very intricate and ineffective due to low homologous recombination frequency (Xie and Yang, 2013). Recently, the very common and effective approaches used for targeted genome editing in plants are CRISPR-Cas9, ZFNs, and TALENs, (Cong et al., 2013; Rabara et al., 2014; Kumar and Jain, 2015). The ZFNs are the synthetic proteins that induced targeted DSBs and facilitated targeted mutagenesis or base substation at specific genomic loci, which alter or may knockout the gene expression (Li et al., 2013a,b). Using ZFNs, the targeted genome modifications can be done as point mutations, insertions, deletions, duplications, inversions, and translocations in numerous organisms (Joung and Sander, 2013). Genome-editing technologies opened several new windows to introduce targeted gene alteration in plants to know the molecular aspects involved in abiotic stress tolerance (Haque et al., 2018).

8.3.1 Clustered regularly interspaced short palindromic repeat (CRISPR)-Cas9 (CRISPR-associated nuclease 9)

The most recent development in the genome engineering approach is CRISPR-Cas9 system, which is derived from the prokaryotic RNA-guided defense system (Sander and Joung, 2014). A single-guide RNA (sgRNA) of 20−22 nucleotides (nt) in length recognizes the target DNA by complementary base pairing in the Cas9 nuclease-mediated cleavage (Sander and Joung, 2014; Kumar and Jain, 2015). A protospacer adjacent motif site (NGG/NAG) at 3′ of the targets is necessary for CRISPR-Cas9−mediated genome engineering. The sgRNA can be designed and synthesized as oligonucleotides that provide high specificity and ease of targeting with minimal or no off-target effects. Cas9 nuclease can target any DNA sequences with 5′-N (20−22)-NGG with altering the guide sequences. With these advantages the system is open to multiplexing and can be utilized to introduce mutations simultaneously into multiple genes or genomic loci which may overcome the problems posed by functional redundancy of genes. CRISPR-Cas9 approach has been successfully utilized in efficient genome editing in bacteria, animals, and plants (Feng et al., 2013a,b; Li et al., 2013a,b; Debbarma et al., 2019). To design the sgRNA(s) for target genes, several web tools have been successfully developed for numerous plant species (Montague et al., 2014). Additionally, some vectors, constructs, and toolkits have also been available for CRISPR-Cas9−mediated genome editing (Kumar and Jain, 2015). Multiplex genome editing via CRISPR-Cas9 system has also been effectively employed in plants (Li et al., 2013a,b; Zhou et al., 2014). Recently Kim et al. (2014) demonstrated that this system could be genotyping the naturally occurring variations that help in differentiating homozygous biallelic mutants from the wild-type plants. Similarly, some studies established the generation of

homozygous transgenic lines in T_1 generation that make it the fastest promising approach in plant genome modification (Zhou et al., 2014; Brooks et al., 2014). This advancement in plant functional genomics can reduce plant breeding or genetic transformation time extensively and generate improved cultivars/transgenic lines with desired traits (Cox et al., 2017). Parallelly, this system also facilitates the production of mutant lines/plants as nontransgenics after delivering such nucleases which help out to succeed as non-GM (genetically modified) and would have an immense impact on plant breeding and biotechnology (Marton et al., 2010).

8.3.2 Targeting-induced local lesions in genomes (TILLING)

Targeting-induced local lesions in genomes is another nontransgenic approach with enormous potentials in functional genomics in plants. It facilitates genome-wide analysis that allows the PCR-based identification of specific mutations in target genomic sequences to produce novel mutant alleles for crop improvements (Gilliham et al., 2017). It takes advantage of conventional insertional mutagenesis and genomic sequences availability and offers quick detection of point mutations as well as functional validation of targeted genes (Akpınar et al., 2013). It has a wide range of applications in almost all plant species inclusive of diploids along with allohexaploids (Chen et al., 2014). Under abiotic stress conditions, plants exhibit diverse phenotypes associated with genotypic variations in their genome sequences (De Lorenzo et al., 2009). This approach, used to identify the natural variations in individuals, is called EcoTILLING. It is a modified high-throughput approach, developed for the screening of SNPs and small indels (Bajaj et al., 2016). It provides information on allelic variants for numerous genes as well as unraveling the intricacy of abiotic stress-tolerance pathways. EcoTILLING approach was successfully used to identify SNPs involved in salt and drought tolerance in rice (Negrao et al., 2011; Yu et al., 2012a,b). Of late, TILLING was used to prove the performance of heat shock factor binding protein-1, where chemically induced mutations disrupted the said protein functions partially and the mutant lines demonstrated improved heat stress tolerance in tomato (Marko et al., 2019). This approach is imperative for better genotypes and target genes selection in abiotic stress tolerance in plants.

8.3.3 Transcription activator-like effector nucleases (TALENs)

TALENs using sequence-specific nucleases became a potential genome-editing system to understand the target gene functions. It comprises a customizable DB domain and nuclease that cause a DSB at target genomic sequences (Sprink et al., 2015). These DSBs are generally repaired via homologous recombination or NHEJ pathway. The pathways allow insertion, deletion, and intended replacements in the target sequences and cause the phenotype variation, which suggests the function of defined genes (Sprink et al., 2015). TALENs have shown a great success rate, but the large size possibly will limit their delivery via recombinant adeno-associated viruses (Gaj et al., 2013).

Transfer DNA (T-DNA) insertional mutagenesis is another approach available to study the functional genomics in plants (Jung and An, 2013). *Agrobacterium*-mediated transformation of T-DNA is able to offer a compelling prospect to target candidate genes in plants. Target gene inactivation can be done using random T-DNA insertions. Large numbers of sequence-indexed T-DNA insertion lines were attained during *Arabidopsis* functional genomics initiatives (https://www.arabidopsis.org/portals/mutants/stockcenters.jsp). In the same way, thousands of flanking sequence tags were deposited during the International Rice Genome Sequencing project that is also available in the public domain (https://tos.nias.affrc.go.jp/). These available mutants are a good source for illuminating metabolic pathways for the functional analysis of genes in plants (Gao and Zhao, 2013).

8.3.4 MicroRNAs (miRNAs)

The small noncoding RNA molecule of 20−22 nt in length, called miRNAs, plays a regulatory role in several processes (Budak et al., 2015). miRNAs bind to the target by regular Watson−Crick base pairing and either direct the cleavage of target transcripts or inhibit the translation, leading to the reduction of target gene expression at the transcriptional or posttranscriptional level. Gene-silencing mechanism mediated by miRNA can regulate the expressions of any gene, TFs, plant hormones, and other signaling pathways related to biotic and abiotic stresses (Curaba et al., 2014). miRNAs have their definite putative targets that direct the regulation of distinct genes and/or TFs involved in stress-tolerance mechanisms. miRNAs have important roles in metabolism and signal transduction that make them significant regulators in drought signaling (Feng et al., 2013a,b). miRNAs gene transcripts called *MIR* can be generally influenced spatially and temporally via cellular signaling factors (Jung et al., 2015). Many conserved miRNAs in plants such as miR159, miR164, miR172, and miR393 regulate the expressions of important TFs that control various cellular pathways

(Ferdous et al., 2015). These are involved in developments and signaling pathways, including auxin signaling, ABA response, antioxidant defense, osmo protection, cell growth, respiration, and photosynthesis (Ding et al., 2013). Numerous signaling genes such as *TIR1*, ARF, *AGO1, MYB33*, and *MYB101* are targeted as well as controlled by drought-responsive miRNAs (Covarrubias and Reyes, 2010). The miRNA expression profiles in response to drought are documented in several plants species, such as *Gossypium hirsutum* (Wang et al., 2013), *Solanum tuberosum* (Zhang et al., 2014), *Panicum virgatum* (Xie et al., 2014), *Sorghum bicolor* (Hamza et al., 2016), *Oryza rufipogon* (Zhang et al., 2016), *Cucumis sativus* (Li et al., 2016), *Triticum turgidum* (Giusti et al., 2017), *Elettaria cardamomum* (Anjali et al., 2017), and *Hordeum vulgare* (Ferdous et al., 2017). miRNAs related to another important stress, that is, heavy metal (cadmium, mercury, manganese, aluminum, and arsenic-responsive miRNAs), are also documented in a number of plant species—*Phaseolus vulgaris* (Valdés-López et al., 2010), *B. napus* (Huang et al., 2010), *Oryza sativa* (Yu et al., 2012a,b), *Glycine soja* (Zeng et al., 2012), *M. truncatula* (Zhou et al., 2012), and *Raphanus sativus* (Xu et al., 2013).

8.3.5 RNA interference (RNAi)

RNAi is a sequence-specific gene-silencing mechanism triggered by the introduction of double-stranded RNA (dsRNA) leading to mRNA degradation. RNAi serves as promising tools in the functional genomics, offering aid in the analysis of gene function by specific knockdown of target mRNA transcript. RNAi pathway is initiated by the enzyme dicer, a conserved member of the RNaseIII gene family, and contains a C-terminal dsRNA binding domain and N-terminal RNA helicase plus two RNaseIII-like domains (Bernstein et al., 2001; Pare and Hobman, 2007). This dicer cleaves dsRNA to short double-stranded fragments of about 21−25 nt in length, depending upon the species (Hammond et al., 2001; Younis et al., 2014). One of the two strands of each fragment, known as the guide strand, is then incorporated into the RNA-induced silencing complex (RISC) and base-pairs with complementary sequences (Redfern et al., 2013). This occurs when a guide strand base-pairs with the mRNA and induces its degradation by argonaute, the catalytic component of the RISC (Riley et al., 2012). The small RNA fragments are known as siRNA which are entirely complementary to the gene to which they are suppressing as they are derived from long dsRNA of the same gene (Sijen et al., 2007). RNAi approach has been successfully employed to accomplish different abiotic stress responses in many crops (Shriram et al., 2016; Kumar et al., 2018). However, the core disadvantage of this approach is that the function of the gene is not entirely inhibited, which facilitates unintended off-target effects leading to misinterpretation of results (Gaj et al., 2013).

8.4 Conclusion

Plants repeatedly combat abiotic stresses in their natural environment that limit plant growth and productivity and become a major threat to food security. Abiotic stress tolerance is a complex trait as plants respond to diverse stresses by activating the complex signal transduction networks and stress-associated genes expressions. A number of plants have developed an intricate signaling network in response to diverse stresses. With the developments in plant functional genomics, research has come up with novel and promising perspectives and several genes related to abiotic stress tolerance have been characterized and are being used to improve stress tolerance. NGS and WGS data of certain important plant species as well as genome editing−based techniques will play important roles in crop improvements. In the near future the plant biotechnologists will have a better understanding of stress-tolerant mechanisms in plants, and farmers will be able to grow high yielding stress-tolerant crops in the fields.

References

Akpınar, B.A., Lucas, S.J., Budak, H., 2013. Genomics approaches for crop improvement against abiotic stress. Sci. World J. 2013.

Akpinar, B.A., Lucas, S., Budak, H., 2017. A large-scale chromosome-specific SNP discovery guideline. Funct. Integr. Genomics 17 (1), 97−105.

Allardyce, J.A., Rookes, J.E., Hussain, H.I., Cahill, D.M., 2013. Transcriptional profiling of Zea mays roots reveals roles for jasmonic acid and terpenoids in resistance against *Phytophthora cinnamomi*. Funct. Integr. Genomics 13 (2), 217−228.

Anjali, N., Nadiya, F., Thomas, J., Sabu, K.K., 2017. Discovery of microRNAs in cardamom (*Elettaria cardamomum* Maton) under drought stress. Dataset Pap. Sci. 2017.

Armbrust, E.V., Berges, J.A., Bowler, C., Green, B.R., Martinez, D., Putnam, N.H., et al., 2004. The genome of the diatom *Thalassiosira pseudonana*: ecology, evolution, and metabolism. Science 306 (5693), 79−86.

Assefa, E., Erusulo, D., 2016. Application of molecular tools in breeding cereal crops for drought tolerance. J. Bio Agri Healthc. 6, 58−68.

Bajaj, D., Srivastava, R., Nath, M., Tripathi, S., Bharadwaj, C., Upadhyaya, H.D., et al., 2016. EcoTILLING-based association mapping efficiently delineates functionally relevant natural allelic variants of candidate genes governing agronomic traits in chickpea. Front. Plant. Sci. 7, 450.

Bartlett, M.K., Detto, M., Pacala, S.W., 2019. Predicting shifts in the functional composition of tropical forests under increased drought and CO_2 from trade-offs among plant hydraulic traits. Ecol. Lett. 22 (1), 67−77.

Battisti, D.S., Naylor, R.L., 2009. Historical warnings of future food insecurity with unprecedented seasonal heat. Science 323 (5911), 240−244.

Bernstein, E., Caudy, A.A., Hammond, S.M., Hannon, G.J., 2001. Role for a *bidentate ribonuclease* in the initiation step of RNA interference. Nature 409 (6818), 363−366.

Bhullar, N.K., Gruissem, W., 2013. Nutritional enhancement of rice for human health: the contribution of biotechnology. Biotechnol. Adv. 31 (1), 50−57.

Blum, A., 2017. Osmotic adjustment is a prime drought stress adaptive engine in support of plant production. Plant, Cell Environ. 40 (1), 4−10.

Breyne, P., Zabeau, M., 2001. Genome-wide expression analysis of plant cell cycle modulated genes. Curr. Opin. Plant. Biol. 4 (2), 136−142.

Brooks, C., Nekrasov, V., Lippman, Z.B., Van Eck, J., 2014. Efficient gene editing in tomato in the first generation using the clustered regularly interspaced short palindromic repeats/CRISPR-associated9 system. Plant. Physiol. 166 (3), 1292−1297.

Budak, H., Hussain, B., Khan, Z., Ozturk, N.Z., Ullah, N., 2015. From genetics to functional genomics: improvement in drought signaling and tolerance in wheat. Front. Plant. Sci. 6, 1012.

Canter, L.W., 2018. Environmental impact of agricultural production activities. CRC Press.

Cao, L., Yu, Y., Ding, X., Zhu, D., Yang, F., Liu, B., et al., 2017. The *Glycine soja* NAC transcription factor GsNAC019 mediates the regulation of plant alkaline tolerance and ABA sensitivity. Plant. Mol. Biol. 95 (3), 253−268.

Challa, S., Neelapu, N.R., 2018. Genome-wide association studies (GWAS) for abiotic stress tolerance in plants. Biochemical, physiological and molecular avenues for combating abiotic stress tolerance in plants. Academic Press, pp. 135−150.

Chaudhary, J., Alisha, A., Bhatt, V., Chandanshive, S., Kumar, N., Mir, Z., et al., 2019. Mutation breeding in tomato: advances, applicability and challenges. Plants 8 (5), 128.

Chawla, K., Barah, P., Kuiper, M., Bones, A.M., 2011. Systems biology: a promising tool to study abiotic stress responses. Omics Plant Abiotic Stress. Tolerance 163−172.

Chen, L., Hao, L., Parry, M.A., Phillips, A.L., Hu, Y.G., 2014. Progress in TILLING as a tool for functional genomics and improvement of crops. J. Integr. Plant. Biol. 56 (5), 425−443.

Chen, J., Chopra, R., Hayes, C., Morris, G., Marla, S., Burke, J., et al., 2017. Genome-wide association study of developing leaves' heat tolerance during vegetative growth stages in a sorghum association panel. Plant. Genome 10 (2).

Cheng, C.K., Au, C.H., Wilke, S.K., Stajich, J.E., Zolan, M.E., Pukkila, P.J., et al., 2013. 5'-serial analysis of gene expression studies reveal a transcriptomic switch during fruiting body development in *Coprinopsis cinerea*. BMC Genomics 14 (1), 195.

Chopra, R., Burow, G., Hayes, C., Emendack, Y., Xin, Z., Burke, J., 2015. Transcriptome profiling and validation of gene based single nucleotide polymorphisms (SNPs) in sorghum genotypes with contrasting responses to cold stress. BMC Genomics 16 (1), 1040.

Cong, L., Ran, F.A., Cox, D., Lin, S., Barretto, R., Habib, N., et al., 2013. Multiplex genome engineering using CRISPR/Cas systems. Science 339 (6121), 819−823.

Covarrubias, A.A., Reyes, J.L., 2010. Post-transcriptional gene regulation of salinity and drought responses by plant microRNAs. Plant Cell Environ. 33 (4), 481−489.

Cox, D.B., Gootenberg, J.S., Abudayyeh, O.O., Franklin, B., Kellner, M.J., Joung, J., et al., 2017. RNA editing with CRISPR-Cas13. Science 358 (6366), 1019−1027.

Cramer, G.R., Urano, K., Delrot, S., Pezzotti, M., Shinozaki, K., 2011. Effects of abiotic stress on plants: a systems biology perspective. BMC Plant. Biol. 11 (1), 163.

Curaba, J., Singh, M.B., Bhalla, P.L., 2014. miRNAs in the crosstalk between phytohormone signalling pathways. J. Exp. Bot. 65 (6), 1425−1438.

De Lorenzo, L., Merchan, F., Laporte, P., Thompson, R., Clarke, J., Sousa, C., et al., 2009. A novel plant leucine-rich repeat receptor kinase regulates the response of *Medicago truncatula* roots to salt stress. Plant. Cell 21 (2), 668−680.

Debbarma, J., Sarki, Y.N., Saikia, B., Boruah, H.P.D., Singha, D.L., Chikkaputtaiah, C., 2019. Ethylene response factor (ERF) family proteins in abiotic stresses and CRISPR−Cas9 genome editing of ERFs for multiple abiotic stress tolerance in crop plants: a review. Mol. Biotechnol. 61 (2), 153−172.

Ding, Y., Tao, Y., Zhu, C., 2013. Emerging roles of microRNAs in the mediation of drought stress response in plants. J. Exp. Bot. 64 (11), 3077−3086.

Dong, W., Song, Y., Zhao, Z., Wei Qiu, N., Liu, X., Guo, W., 2017. The *Medicago truncatula* R2R3-MYB transcription factor gene MtMYBS1 enhances salinity tolerance when constitutively expressed in *Arabidopsis thaliana*. Biochemical Biophysical Res. Commun. 490 (2), 225−230.

Dou, T.X., Hu, C.H., Sun, X.X., Shao, X.H., Wu, J.H., Ding, L.J., et al., 2016. MpMYBS3 as a crucial transcription factor of cold signaling confers the cold tolerance of banana. Plant. Cell Tissue Organ. Cult. (PCTOC) 125 (1), 93−106.

Dreccer, M.F., Fainges, J., Whish, J., Ogbonnaya, F.C., Sadras, V.O., 2018. Comparison of sensitive stages of wheat, barley, canola, chickpea and field pea to temperature and water stress across Australia. Agric. For. Meteorol. 248, 275−294.

Dugas, D.V., Monaco, M.K., Olson, A., Klein, R.R., Kumari, S., Ware, D., et al., 2011. Functional annotation of the transcriptome of Sorghum bicolor in response to osmotic stress and abscisic acid. BMC Genomics 12 (1), 514.

Edwards, D., 2016. The impact of genomics technology on adapting plants to climate change. Plant genomics and climate change. Springer, New York, NY, pp. 173−178.

Feist, A.M., Palsson, B.Ø., 2008. The growing scope of applications of genome-scale metabolic reconstructions using Escherichia coli. Nat. Biotechnol. 26 (6), 659–667.

Feng, H., Zhang, Q., Li, H., Wang, X., Wang, X., Duan, X., et al., 2013a. vsiRNAs derived from the miRNA-generating sites of pri-tae-miR159a based on the BSMV system play positive roles in the wheat response to *Puccinia striiformis* f. sp. *tritici* through the regulation of taMyb3 expression. Plant. Physiol. Biochem. 68, 90–95.

Feng, Z., Zhang, B., Ding, W., Liu, X., Yang, D.L., Wei, P., et al., 2013b. Efficient genome editing in plants using a CRISPR/Cas system. Cell Res. 23 (10), 1229–1232.

Ferdous, J., Hussain, S.S., Shi, B.J., 2015. Role of micro RNA s in plant drought tolerance. Plant. Biotechnol. J. 13 (3), 293–305.

Ferdous, J., Sanchez-Ferrero, J.C., Langridge, P., Milne, L., Chowdhury, J., Brien, C., et al., 2017. Differential expression of microRNAs and potential targets under drought stress in barley. Plant Cell Environ. 40 (1), 11–24.

Franco-Zorrilla, J.M., López-Vidriero, I., Carrasco, J.L., Godoy, M., Vera, P., Solano, R., 2014. DNA-binding specificities of plant transcription factors and their potential to define target genes. Proc. Natl Acad. Sci. 111 (6), 2367–2372.

Fu, X., Fu, N., Guo, S., Yan, Z., Xu, Y., Hu, H., et al., 2009. Estimating accuracy of RNA-Seq and microarrays with proteomics. BMC Genomics 10 (1), 161.

Gaj, T., Gersbach, C.A., Barbas III, C.F., 2013. ZFN, TALEN, and CRISPR/Cas-based methods for genome engineering. Trends Biotechnol. 31 (7), 397–405.

Galagan, J.E., Calvo, S.E., Borkovich, K.A., Selker, E.U., Read, N.D., Jaffe, D., et al., 2003. The genome sequence of the filamentous fungus *Neurospora crassa*. Nature 422 (6934), 859–868.

Ganal, M.W., Altmann, T., Röder, M.S., 2009. SNP identification in crop plants. Curr. Opin. Plant. Biol. 12 (2), 211–217.

Gao, Y., Zhao, Y., 2013. Epigenetic suppression of T-DNA insertion mutants in Arabidopsis. Mol. Plant. 6 (2), 539–545.

Gao, J., Wang, S., Zhou, Z., Wang, S., Dong, C., Mu, C., et al., 2019. Linkage mapping and genome-wide association reveal candidate genes conferring thermotolerance of seed-set in maize. J. Exp. Bot. 70 (18), 4849–4864.

Garg, D., Sareen, S., Dalal, S., Tiwari, R., Singh, R., 2012. Heat shock protein based SNP marker for terminal heat stress in wheat (*Triticum aestivum* L.). Aust. J. Crop. Sci. 6 (11), 1516.

Garg, R., Shankar, R., Thakkar, B., Kudapa, H., Krishnamurthy, L., Mantri, N., et al., 2016. Transcriptome analyses reveal genotype-and developmental stage-specific molecular responses to drought and salinity stresses in chickpea. Sci. Rep. 6, 19228.

Ghosh, G., Mukhopadhyay, D.K., 2019. Human health hazards due to arsenic and fluoride contamination in drinking water and food chain. Groundw. Dev. Manag. Springer, Cham, pp. 351–369.

Gilliham, M., Able, J.A., Roy, S.J., 2017. Translating knowledge about abiotic stress tolerance to breeding programmes. Plant. J. 90 (5), 898–917.

Giusti, L., Mica, E., Bertolini, E., De Leonardis, A.M., Faccioli, P., Cattivelli, L., et al., 2017. microRNAs differentially modulated in response to heat and drought stress in durum wheat cultivars with contrasting water use efficiency. Funct. Integr. genomics 17 (2-3), 293–309.

Gong, Q., Li, P., Ma, S., Indu Rupassara, S., Bohnert, H.J., 2005. Salinity stress adaptation competence in the extremophile *Thellungiella halophila* in comparison with its relative *Arabidopsis thaliana*. Plant. J. 44 (5), 826–839.

González-Schain, N., Dreni, L., Lawas, L.M., Galbiati, M., Colombo, L., Heuer, S., et al., 2016. Genome-wide transcriptome analysis during anthesis reveals new insights into the molecular basis of heat stress responses in tolerant and sensitive rice varieties. Plant. Cell Physiol. 57 (1), 57–68.

Greenham, K., Guadagno, C.R., Gehan, M.A., Mockler, T.C., Weinig, C., Ewers, B.E., et al., 2017. Temporal network analysis identifies early physiological and transcriptomic indicators of mild drought in *Brassica rapa*. Elife 6, e29655.

Gul, A., Ahad, A., Akhtar, S., Ahmad, Z., Rashid, B., Husnain, T., 2016. Microarray: gateway to unravel the mystery of abiotic stresses in plants. Biotechnol. Lett. 38 (4), 527–543.

Guo, T., Yang, J., Li, D., Sun, K., Luo, L., Xiao, W., et al., 2019. Integrating GWAS, QTL, mapping and RNA-seq to identify candidate genes for seed vigor in rice (*Oryza sativa* L.). Mol. Breed. 39 (6), 87.

Hall, D., Tegström, C., Ingvarsson, P.K., 2010. Using association mapping to dissect the genetic basis of complex traits in plants. Brief. Funct. Genomics 9 (2), 157–165.

Hamilton, J.P., Robin Buell, C., 2012. Advances in plant genome sequencing. Plant. J. 70 (1), 177–190.

Nobuta, K., Venu, R.C., Lu, C., Beló, A., Vemaraju, K., Kulkarni, K., et al., 2007. An expression atlas of rice mRNAs and small RNAs. Nat. Biotechnol. 25 (4), 473–477.

Hammond, S.M., Caudy, A.A., Hannon, G.J., 2001. Post-transcriptional gene silencing by double-stranded RNA. Nat. Rev. Genet. 2 (2), 110–119.

Hamza, N.B., Sharma, N., Tripathi, A., Sanan-Mishra, N., 2016. MicroRNA expression profiles in response to drought stress in Sorghum bicolor. Gene Expr. Patterns 20 (2), 88–98.

Haque, E., Taniguchi, H., Hassan, M., Bhowmik, P., Karim, M.R., Śmiech, M., et al., 2018. Application of CRISPR/Cas9 genome editing technology for the improvement of crops cultivated in tropical climates: recent progress, prospects, and challenges. Front. Plant. Sci. 9, 617.

Hasanuzzaman, M., Roychowdhury, R., Karmakar, J., Dey, N., Nahar, K., Fujita, M., 2015. Recent advances in biotechnology and genomic approaches for abiotic stress tolerance in crop plants. Genomics and proteomics: concepts, technologies and applications. Apple Academic Press, Canada, pp. 333–366.

Hawkins, C., Caruana, J., Li, J., Zawora, C., Darwish, O., Wu, J., et al., 2017. An eFP browser for visualizing strawberry fruit and flower transcriptomes. Hortic. Res. 4 (1), 1–8.

Hirakawa, H., Shirasawa, K., Miyatake, K.O.J.I., Nunome, T., Negoro, S., Ohyama, A.K.I.O., et al., 2014. Draft genome sequence of eggplant (Solanum melongena L.): the representative *Solanum* species indigenous to the old world. DNA Res. 21 (6), 649–660.

Huang, S.Q., Xiang, A.L., Che, L.L., Chen, S., Li, H., Song, J.B., et al., 2010. A set of miRNAs from *Brassica napus* in response to sulphate deficiency and cadmium stress. Plant. Biotechnol. J. 8 (8), 887−899.

Huang, M., Chai, L., Jiang, D., Zhang, M., Zhao, Y., Huang, Y., 2019. Increasing aridity affects soil archaeal communities by mediating soil niches in semi-arid regions. Sci. Total. Environ. 647, 699−707.

Isayenkov, S.V., Maathuis, F.J., 2019. Plant salinity stress: many unanswered questions remain. Front. Plant. Sci. 10.

Jin, C., Li, K.Q., Xu, X.Y., Zhang, H.P., Chen, H.X., Chen, Y.H., et al., 2017. A novel NAC transcription factor, PbeNAC1, of *Pyrus betulifolia* confers cold and drought tolerance via interacting with PbeDREBs and activating the expression of stress-responsive genes. Front. Plant. Sci. 8, 1049.

Joung, J.K., Sander, J.D., 2013. TALENs: a widely applicable technology for targeted genome editing. Nat. Rev. Mol. Cell Biol. 14 (1), 49−55.

Jung, K.H., An, G., 2013. Functional characterization of rice genes using a gene-indexed T-DNA insertional mutant population. Rice protocol. Humana Press, Totowa, NJ, pp. 57−67.

Jung, I.L., Ryu, M., Cho, S.K., Shah, P., Lee, J.H., Bae, H., et al., 2015. Cesium toxicity alters MicroRNA processing and AGO1 expressions in *Arabidopsis thaliana*. PLoS One 10 (5).

Kamburova, V.S., Nikitina, E.V., Shermatov, S.E., Buriev, Z.T., Kumpatla, S.P., Emani, C., et al., 2017. Genome editing in plants: an overview of tools and applications. Int. J. Agron. 2017.

Khan, S.A., Li, M.Z., Wang, S.M., Yin, H.J., 2018. Revisiting the role of plant transcription factors in the battle against abiotic stress. Int. J. Mol. Sci. 19 (6), 1634.

Kilasi, N.L., Singh, J., Vallejos, C.E., Ye, C., Jagadish, S.V., Kusolwa, P., et al., 2018. Heat stress tolerance in rice (*Oryza sativa* L.): identification of quantitative trait loci and candidate genes for seedling growth under heat stress. Front. Plant. Sci. 9, 1578.

Kim, J.M., Kim, D., Kim, S., Kim, J.S., 2014. Genotyping with CRISPR-Cas-derived RNA-guided endonucleases. Nat. Commun. 5, 3157.

Kim, J.M., Sasaki, T., Ueda, M., Sako, K., Seki, M., 2015. Chromatin changes in response to drought, salinity, heat, and cold stresses in plants. Front. Plant. Sci. 6, 114.

Kim, C.Y., Vo, K.T.X., Nguyen, C.D., Jeong, D.H., Lee, S.K., Kumar, M., et al., 2016. Functional analysis of a cold-responsive rice WRKY gene, OsWRKY71. Plant. Biotechnol. Rep. 10 (1), 13−23.

Kim, J.M., To, T.K., Matsui, A., Tanoi, K., Kobayashi, N.I., Matsuda, F., et al., 2017. Acetate-mediated novel survival strategy against drought in plants. Nat. Plants 3 (7), 17097.

Klepikova, A.V., Kasianov, A.S., Gerasimov, E.S., Logacheva, M.D., Penin, A.A., 2016. A high resolution map of the *Arabidopsis thaliana* developmental transcriptome based on RNA-seq profiling. Plant. J. 88 (6), 1058−1070.

Kogan, F., Guo, W., Yang, W., 2019. Drought and food security prediction from NOAA new generation of operational satellites. Geomatics Natural Hazards Risk 10 (1), 651−666.

Koryachko, A., Matthiadis, A., Ducoste, J.J., Tuck, J., Long, T.A., Williams, C., 2015. Computational approaches to identify regulators of plant stress response using high-throughput gene expression data. Curr. Plant. Biol. 3, 20−29.

Kudapa, H., Ramalingam, A., Nayakoti, S., Chen, X., Zhuang, W.J., Liang, X., et al., 2013. Functional genomics to study stress responses in crop legumes: progress and prospects. Funct. Plant. Biol. 40 (12), 1221−1233.

Kumar, V., Jain, M., 2015. The CRISPR−Cas system for plant genome editing: advances and opportunities. J. Exp. Bot. 66 (1), 47−57.

Kumar, V., Khare, T., Shriram, V., Wani, S.H., 2018. Plant small RNAs: the essential epigenetic regulators of gene expression for salt-stress responses and tolerance. Plant. Cell Rep. 37 (1), 61−75.

Kundu, P., Gill, R., Ahlawat, S., Anjum, N.A., Sharma, K.K., Ansari, A.A., et al., 2018. Targeting the redox regulatory mechanisms for abiotic stress tolerance in crops. Biochemical, physiological and molecular avenues for combating abiotic stress in plants. Academic Press, pp. 151−220.

Le, D.T., Nishiyama, R., Watanabe, Y., Tanaka, M., Seki, M., Ham, L.H., et al., 2012. Differential gene expression in soybean leaf tissues at late developmental stages under drought stress revealed by genome-wide transcriptome analysis. PLoS One 7 (11).

Lesk, C., Rowhani, P., Ramankutty, N., 2016. Influence of extreme weather disasters on global crop production. Nature 529 (7584), 84−87.

Li, J.F., Norville, J.E., Aach, J., McCormack, M., Zhang, D., Bush, J., et al., 2013a. Multiplex and homologous recombination−mediated genome editing in *Arabidopsis* and *Nicotiana benthamiana* using guide RNA and Cas9. Nat. Biotechnol. 31 (8), 688−691.

Li, W.T., He, M., Wang, J., Wang, Y.P., 2013b. Zinc finger protein (ZFP) in plants-A review. Plant. Omics 6 (6), 474.

Li, F., Fan, G., Wang, K., Sun, F., Yuan, Y., Song, G., et al., 2014. Genome sequence of the cultivated cotton *Gossypium arboreum*. Nat. Genet. 46 (6), 567−572.

Li, C., Li, Y., Bai, L., He, C., Yu, X., 2016. Dynamic expression of miRNAs and their Targets in the response to drought stress of grafted cucumber seedlings. Horticultural Plant. J. 2 (1), 41−49.

Li, L., Mao, X., Wang, J., Chang, X., Reynolds, M., Jing, R., 2019. Genetic dissection of drought and heat-responsive agronomic traits in wheat. Plant Cell Environ. 42 (9), 2540−2553.

Libault, M., Pingault, L., Zogli, P., Schiefelbein, J., 2017. Plant systems biology at the single-cell level. Trends Plant. Sci. 22 (11), 949−960.

Liu, S., Trapnell, C., 2016. Single-cell transcriptome sequencing: recent advances and remaining challenges. F1000Research 5.

Liu, B., Hong, Y.B., Zhang, Y.F., Li, X.H., Huang, L., Zhang, H.J., et al., 2014a. Tomato WRKY transcriptional factor SlDRW1 is required for disease resistance against *Botrytis cinerea* and tolerance to oxidative stress. Plant. Sci. 227, 145−156.

Liu, Z., Zhang, M., Kong, L., Lv, Y., Zou, M., Lu, G., et al., 2014b. Genome-wide identification, phylogeny, duplication, and expression analyses of two-component system genes in Chinese cabbage (*Brassica rapa* ssp. *pekinensis*). DNA Res. 21 (4), 379−396.

Lu, F., Romay, M.C., Glaubitz, J.C., Bradbury, P.J., Elshire, R.J., Wang, T., et al., 2015. High-resolution genetic mapping of maize pan-genome sequence anchors. Nat. Commun. 6 (1), 1−8.

Mammadov, J., Aggarwal, R., Buyyarapu, R., Kumpatla, S., 2012. SNP markers and their impact on plant breeding. Int. J. Plant. Genomics 2012.
Marko, D., El-shershaby, A., Carriero, F., Summerer, S., Petrozza, A., Iannacone, R., et al., 2019. Identification and characterization of a thermotolerant TILLING allele of heat shock binding protein 1 in tomato. Genes 10 (7), 516.
Martínez-Andújar, C., Pluskota, W.E., Bassel, G.W., Asahina, M., Pupel, P., Nguyen, T.T., et al., 2012. Mechanisms of hormonal regulation of endosperm cap-specific gene expression in tomato seeds. Plant. J. 71 (4), 575–586.
Marton, I., Zuker, A., Shklarman, E., Zeevi, V., Tovkach, A., Roffe, S., et al., 2010. Nontransgenic genome modification in plant cells. Plant. Physiol. 154 (3), 1079–1087.
Masoudi, B., Mardi, M., Hervan, E.M., Bihamta, M.R., Naghavi, M.R., Nakhoda, B., et al., 2015. QTL mapping of salt tolerance traits with different effects at the seedling stage of bread wheat. Plant. Mol. Biol. Report. 33 (6), 1790–1803.
Matsui, A., Ishida, J., Morosawa, T., Mochizuki, Y., Kaminuma, E., Endo, T.A., et al., 2008. Arabidopsis transcriptome analysis under drought, cold, high-salinity and ABA treatment conditions using a tiling array. Plant. Cell Physiol. 49 (8), 1135–1149.
Matsumura, H., Urasaki, N., Yoshida, K., Krüger, D.H., Kahl, G., Terauchi, R., 2012. SuperSAGE: powerful serial analysis of gene expression. RNA abundance analysis. Humana Press, Totowa, NJ, pp. 1–17.
Mickelbart, M.V., Hasegawa, P.M., Bailey-Serres, J., 2015. Genetic mechanisms of abiotic stress tolerance that translate to crop yield stability. Nat. Rev. Genet. 16 (4), 237–251.
Mondini, L., Nachit, M., Porceddu, E., Pagnotta, M.A., 2012. Identification of SNP mutations in DREB1, HKT1, and WRKY1 genes involved in drought and salt stress tolerance in durum wheat (*Triticum turgidum* L. var. *durum*). Omics: A J. Integr. Biol. 16 (4), 178–187.
Montague, T.G., Cruz, J.M., Gagnon, J.A., Church, G.M., Valen, E., 2014. CHOPCHOP: a CRISPR/Cas9 and TALEN web tool for genome editing. Nucleic Acids Res. 42 (W1), W401–W407.
Munns, R., Tester, M., 2008. Mechanisms of salinity tolerance. Annu. Rev. Plant. Biol. 59, 651–681.
Nakaminami, K., Matsui, A., Shinozaki, K., Seki, M., 2012. RNA regulation in plant abiotic stress responses. Biochimica et. Biophysica Acta (BBA)-Gene Regulatory Mechanisms 1819 (2), 149–153.
Nakaminami, K., Okamoto, M., Higuchi-Takeuchi, M., Yoshizumi, T., Yamaguchi, Y., Fukao, Y., et al., 2018. AtPep3 is a hormone-like peptide that plays a role in the salinity stress tolerance of plants. Proc. Natl Acad. Sci. 115 (22), 5810–5815.
Nakano, M., Nobuta, K., Vemaraju, K., Tej, S.S., Skogen, J.W., Meyers, B.C., 2006. Plant MPSS databases: signature-based transcriptional resources for analyses of mRNA and small RNA. Nucleic Acids Res. 34 (Suppl_1), D731–D735.
Nakashima, K., Yamaguchi-Shinozaki, K., Shinozaki, K., 2014. The transcriptional regulatory network in the drought response and its crosstalk in abiotic stress responses including drought, cold, and heat. Front. Plant. Sci. 5, 170.
Negrao, S., Almadanim, C., Pires, I., McNally, K.L., Oliveira, M.M., 2011. Use of EcoTILLING to identify natural allelic variants of rice candidate genes involved in salinity tolerance. Plant. Genet. Resour. 9 (2), 300–304.
Ni, Y., Aghamirzaie, D., Elmarakeby, H., Collakova, E., Li, S., Grene, R., et al., 2016. A machine learning approach to predict gene regulatory networks in seed development in Arabidopsis. Front. Plant. Sci. 7, 1936.
Ozsolak, F., Milos, P.M., 2011. RNA sequencing: advances, challenges and opportunities. Nat. Rev. Genet. 12 (2), 87–98.
Pare, J.M., Hobman, T.C., 2007. Dicer: structure, function and role in RNA-dependent gene-silencing pathways. Industrial enzymes. Springer, Dordrecht, pp. 421–438.
Patishtan, J., Hartley, T.N., Fonseca de Carvalho, R., Maathuis, F.J., 2018. Genome-wide association studies to identify rice salt-tolerance markers. Plant Cell Environ. 41 (5), 970–982.
Phukan, U.J., Jeena, G.S., Shukla, R.K., 2016. WRKY transcription factors: molecular regulation and stress responses in plants. Front. Plant. Sci. 7, 760.
Proshad, R., Kormoker, T., Mursheed, N., Islam, M.M., Bhuyan, M.I., Islam, M.S., et al., 2018. Heavy metal toxicity in agricultural soil due to rapid industrialization in Bangladesh: a review. Int. J. Adv. Geosci. 6 (1), 83–88.
Quijano, C.D., Brunner, S., Keller, B., Gruissem, W., Sautter, C., 2015. The environment exerts a greater influence than the transgene on the transcriptome of field-grown wheat expressing the Pm3b allele. Transgenic Res. 24 (1), 87–97.
Rabara, R.C., Tripathi, P., Rushton, P.J., 2014. The potential of transcription factor-based genetic engineering in improving crop tolerance to drought. Omics: A J. Integr. Biol. 18 (10), 601–614.
Raftery, A.E., Zimmer, A., Frierson, D.M., Startz, R., Liu, P., 2017. Less than 2 C warming by 2100 unlikely. Nat. Clim. Change 7 (9), 637.
Rahaman, M., Mamidi, S., Rahman, M., 2018. Genome-wide association study of heat stress-tolerance traits in spring-type *Brassica napus* L. under controlled conditions. Crop J. 6 (2), 115–125.
Rahman, M., Rahmat, Z., Gul, M., Zafar, Y., 2016. Plant functional genomics: approaches and applications, Applied molecular biotechnology: the next generation of genetic engineering, 1st edn. CRC Press, Boca Raton, FL, pp. 157–186.
Ramakrishna, C., Singh, S., Raghavendrarao, S., Padaria, J.C., Mohanty, S., Sharma, T.R., et al., 2018. The membrane tethered transcription factor EcbZIP17 from finger millet promotes plant growth and enhances tolerance to abiotic stresses. Sci. Rep. 8 (1), 1–14.
Rasheed, S., Bashir, K., Matsui, A., Tanaka, M., Seki, M., 2016. Transcriptomic analysis of soil-grown *Arabidopsis thaliana* roots and shoots in response to a drought stress. Front. Plant. Sci. 7, 180.
Redfern, A.D., Colley, S.M., Beveridge, D.J., Ikeda, N., Epis, M.R., Li, X., et al., 2013. RNA-induced silencing complex (RISC) Proteins PACT, TRBP, and Dicer are SRA binding nuclear receptor coregulators. Proc. Natl Acad. Sci. 110 (16), 6536–6541.
Richards, C.L., Rosas, U., Banta, J., Bhambhra, N., Purugganan, M.D., 2012. Genome-wide patterns of Arabidopsis gene expression in nature. PLoS Genet. 8 (4).

Riley, K.J., Yario, T.A., Steitz, J.A., 2012. Association of Argonaute proteins and microRNAs can occur after cell lysis. Rna 18 (9), 1581–1585.
Ruggieri, V., Calafiore, R., Schettini, C., Rigano, M.M., Olivieri, F., Frusciante, L., et al., 2019. Exploiting genetic and genomic resources to enhance heat-tolerance in tomatoes. Agronomy 9 (1), 22.
Sander, J.D., Joung, J.K., 2014. CRISPR-Cas systems for editing, regulating and targeting genomes. Nat. Biotechnol. 32 (4), 347.
Sato, Y., Antonio, B.A., Namiki, N., Takehisa, H., Minami, H., Kamatsuki, K., et al., 2010. RiceXPro: a platform for monitoring gene expression in japonica rice grown under natural field conditions. Nucleic Acids Res. 39 (Suppl_1), D1141–D1148.
Schuenemann, V.J., Bos, K., DeWitte, S., Schmedes, S., Jamieson, J., Mittnik, A., et al., 2011. Targeted enrichment of ancient pathogens yielding the pPCP1 plasmid of *Yersinia pestis* from victims of the Black Death. Proc. Natl Acad. Sci. 108 (38), E746–E752.
Shah, K., Nahakpam, S., Chaturvedi, V., Singh, P., 2019. Cadmium-Induced anatomical abnormalities in plants. Cadmium toxicity and tolerance in plants. Academic Press, pp. 111–139.
Sharp, R.E., Poroyko, V., Hejlek, L.G., Spollen, W.G., Springer, G.K., Bohnert, H.J., et al., 2004. Root growth maintenance during water deficits: physiology to functional genomics. J. Exp. Bot 55 (407), 2343–2351.
Shriram, V., Kumar, V., Devarumath, R.M., Khare, T.S., Wani, S.H., 2016. MicroRNAs as potential targets for abiotic stress tolerance in plants. Front. Plant. Sci. 7, 817.
Shulse, C.N., Cole, B.J., Ciobanu, D., Lin, J., Yoshinaga, Y., Gouran, M., et al., 2019. High-throughput single-cell transcriptome profiling of plant cell types. Cell Rep. 27 (7), 2241–2247.
Sijen, T., Steiner, F.A., Thijssen, K.L., Plasterk, R.H., 2007. Secondary siRNAs result from unprimed RNA synthesis and form a distinct class. Science 315 (5809), 244–247.
Singh, A., Siddappa, S., Bhardwaj, V., Singh, B., Kumar, D., Singh, B.P., 2015. Expression profiling of potato cultivars with contrasting tuberization at elevated temperature using microarray analysis. Plant. Physiol. Biochem. 97, 108–116.
Sonah, H., O'Donoughue, L., Cober, E., Rajcan, I., Belzile, F., 2015. Identification of loci governing eight agronomic traits using a GBS-GWAS approach and validation by QTL mapping in soya bean. Plant. Biotechnol. J. 13 (2), 211–221.
Sonah, H., Zhang, X., Deshmukh, R.K., Borhan, M.H., Fernando, W.G., Bélanger, R.R., 2016. Comparative transcriptomic analysis of virulence factors in *Leptosphaeria maculans* during compatible and incompatible interactions with canola. Front. Plant. Sci. 7, 1784.
Song, X., Li, Y., Hou, X., 2013. Genome-wide analysis of the AP2/ERF transcription factor superfamily in Chinese cabbage (Brassica rapa ssp. pekinensis). BMC Genomics 14 (1), 573.
Sprink, T., Metje, J., Hartung, F., 2015. Plant genome editing by novel tools: TALEN and other sequence specific nucleases. Curr. Opin. Biotechnol. 32, 47–53.
Sreenivasulu, N., Sopory, S.K., Kishor, P.K., 2007. Deciphering the regulatory mechanisms of abiotic stress tolerance in plants by genomic approaches. Gene 388 (1-2), 1–13.
Sun, X.C., Gao, Y.F., Li, H.R., Yang, S.Z., Liu, Y.S., 2015. Over-expression of SlWRKY39 leads to enhanced resistance to multiple stress factors in tomato. J. Plant. Biol. 58 (1), 52–60.
Takahashi, F., Shinozaki, K., 2019. Long-distance signaling in plant stress response. Curr. Opin. Plant. Biol. 47, 106–111.
Takahashi, F., Suzuki, T., Osakabe, Y., Betsuyaku, S., Kondo, Y., Dohmae, N., et al., 2018. A small peptide modulates stomatal control via abscisic acid in long-distance signalling. Nature 556 (7700), 235–238.
Tardieu, F., Simonneau, T., Muller, B., 2018. The physiological basis of drought tolerance in crop plants: a scenario-dependent probabilistic approach. Annu. Rev. Plant. Biol. 69, 733–759.
Teotia, S., Singh, D., Tang, X., Tang, G., 2016. Essential RNA-based technologies and their applications in plant functional genomics. Trends Biotechnol. 34 (2), 106–123.
Urano, K., Kurihara, Y., Seki, M., Shinozaki, K., 2010. 'Omics' analyses of regulatory networks in plant abiotic stress responses. Curr. Opin. Plant. Biol. 13 (2), 132–138.
Valdés-López, O., Yang, S.S., Aparicio-Fabre, R., Graham, P.H., Reyes, J.L., Vance, C.P., et al., 2010. MicroRNA expression profile in common bean (Phaseolus *vulgaris*) under nutrient deficiency stresses and manganese toxicity. N. Phytol. 187 (3), 805–818.
Varshney, R.K., Hoisington, D.A., Tyagi, A.K., 2006. Advances in cereal genomics and applications in crop breeding. Trends Biotechnol. 24 (11), 490–499.
Varshney, R.K., Saxena, R.K., Upadhyaya, H.D., Khan, A.W., Yu, Y., Kim, C., et al., 2017. Whole-genome resequencing of 292 pigeon pea accessions identifies genomic regions associated with domestication and agronomic traits. Nat. Genet. 49 (7), 1082.
Vega-Sánchez, M.E., Gowda, M., Wang, G.L., 2007. Tag-based approaches for deep transcriptome analysis in plants. Plant. Sci. 173 (4), 371–380.
Wang, M., Wang, Q., Zhang, B., 2013. Response of miRNAs and their targets to salt and drought stresses in cotton (*Gossypium hirsutum* L.). Gene 530 (1), 26–32.
Wang, H., Wang, H., Shao, H., Tang, X., 2016b. Recent advances in utilizing transcription factors to improve plant abiotic stress tolerance by transgenic technology. Front. Plant. Sci. 7, 67.
Wei, T., Deng, K., Liu, D., Gao, Y., Liu, Y., Yang, M., et al., 2016. Ectopic expression of DREB transcription factor, AtDREB1A, confers tolerance to drought in transgenic *Salvia miltiorrhiza*. Plant. Cell Physiol. 57 (8), 1593–1609.
Xie, K., Yang, Y., 2013. RNA-guided genome editing in plants using a CRISPR–Cas system. Mol. Plant. 6 (6), 1975–1983.
Xie, F., Stewart Jr, C.N., Taki, F.A., He, Q., Liu, H., Zhang, B., 2014. High-throughput deep sequencing shows that micro RNA s play important roles in switchgrass responses to drought and salinity stress. Plant. Biotechnol. J. 12 (3), 354–366.
Xu, L., Wang, Y., Zhai, L., Xu, Y., Wang, L., Zhu, X., et al., 2013. Genome-wide identification and characterization of cadmium-responsive microRNAs and their target genes in radish (*Raphanus sativus* L.) roots. J. Exp. Bot 64 (14), 4271–4287.

Yamasaki, K., Kigawa, T., Seki, M., Shinozaki, K., Yokoyama, S., 2013. DNA-binding domains of plant-specific transcription factors: structure, function, and evolution. Trends Plant. Sci. 18 (5), 267–276.

Younis, A., Siddique, M.I., Kim, C.K., Lim, K.B., 2014. RNA interference (RNAi) induced gene silencing: a promising approach of hi-tech plant breeding. Int. J. Biol. Sci. 10 (10), 1150.

Yu, S., Liao, F., Wang, F., Wen, W., Li, J., Mei, H., et al., 2012a. Identification of rice transcription factors associated with drought tolerance using the ecotilling method. PLoS One 7 (2).

Yu, L.J., Luo, Y.F., Liao, B., Xie, L.J., Chen, L., Xiao, S., et al., 2012b. Comparative transcriptome analysis of transporters, phytohormone and lipid metabolism pathways in response to arsenic stress in rice (*Oryza sativa*). N. Phytol. 195 (1), 97–112.

Zafar, S.A., Hameed, A., Nawaz, M.A., Wei, M.A., Noor, M.A., Hussain, M., 2018. Mechanisms and molecular approaches for heat tolerance in rice (*Oryza sativa* L.) under climate change scenario. J. Integr. Agric. 17 (4), 726–738.

Zandalinas, S.I., Mittler, R., Balfagón, D., Arbona, V., Gómez-Cadenas, A., 2018. Plant adaptations to the combination of drought and high temperatures. Physiologia Plant. 162 (1), 2–12.

Zeng, Q.Y., Yang, C.Y., Ma, Q.B., Li, X.P., Dong, W.W., Nian, H., 2012. Identification of wild soybean miRNAs and their target genes responsive to aluminum stress. BMC Plant. Biol. 12 (1), 182.

Zhang, H., Mao, X., Zhang, J., Chang, X., Jing, R., 2013. Single-nucleotide polymorphisms and association analysis of drought-resistance gene TaSnRK2. 8 in common wheat. Plant. Physiol. Biochem. 70, 174–181.

Zhang, N., Yang, J., Wang, Z., Wen, Y., Wang, J., He, W., et al., 2014. Identification of novel and conserved microRNAs related to drought stress in potato by deep sequencing. PLoS One 9 (4).

Zhang, F., Luo, X., Zhou, Y., Xie, J., 2016. Genome-wide identification of conserved microRNA and their response to drought stress in Dongxiang wild rice (*Oryza rufipogon* Griff.). Biotechnol. Lett. 38 (4), 711–721.

Zhao, Y., Zhou, Y., Jiang, H., Li, X., Gan, D., Peng, X., et al., 2011. Systematic analysis of sequences and expression patterns of drought-responsive members of the HD-Zip gene family in maize. PLoS One 6 (12).

Zhou, Z.S., Zeng, H.Q., Liu, Z.P., Yang, Z.M., 2012. Genome-wide identification of *Medicago truncatula* microRNAs and their targets reveals their differential regulation by heavy metal. Plant Cell Environ. 35 (1), 86–99.

Zhou, H., Liu, B., Weeks, D.P., Spalding, M.H., Yang, B., 2014. Large chromosomal deletions and heritable small genetic changes induced by CRISPR/Cas9 in rice. Nucleic Acids Res. 42 (17), 10903–10914.

Zhou, R., Hyldgaard, B., Yu, X., Rosenqvist, E., Ugarte, R.M., Yu, S., et al., 2018. Phenotyping of faba beans (*Vicia faba* L.) under cold and heat stresses using chlorophyll fluorescence. Euphytica 214 (4), 68.

Zörb, C., Geilfus, C.M., Dietz, K.J., 2019. Salinity and crop yield. Plant. Biol. 21, 31–38.

View publication stats

Springer Protocols

A. Sankaranarayanan
Natarajan Amaresan
Mitesh Kumar Dwivedi *Editors*

Endophytic Microbes: Isolation, Identification, and Bioactive Potentials

Springer

SPRINGER PROTOCOLS HANDBOOKS

For further volumes:
http://www.springer.com/series/8623

Springer Protocols Handbooks collects a diverse range of step-by-step laboratory methods and protocols from across the life and biomedical sciences. Each protocol is provided in the Springer Protocol format: readily-reproducible in a step-by-step fashion. Each protocol opens with an introductory overview, a list of the materials and reagents needed to complete the experiment, and is followed by a detailed procedure supported by a helpful notes section offering tips and tricks of the trade as well as troubleshooting advice. With a focus on large comprehensive protocol collections and an international authorship, *Springer Protocols Handbooks* are a valuable addition to the laboratory.

Endophytic Microbes: Isolation, Identification, and Bioactive Potentials

Edited by

A. Sankaranarayanan

Department of Life Sciences, Sri Sathya Sai University for Human Excellence, Navanihal, Kamalapura, Kalaburagi, Karnataka, India

Natarajan Amaresan and Mitesh Kumar Dwivedi

C.G. Bhakta Institute of Biotechnology, Uka Tarsadia University, Surat, Gujarat, India

Humana Press

Editors
A. Sankaranarayanan
Department of Life Sciences
Sri Sathya Sai University for Human Excellence
Navanihal, Kamalapura
Kalaburagi, Karnataka, India

Mitesh Kumar Dwivedi
C.G. Bhakta Institute of Biotechnology
Uka Tarsadia University
Surat, Gujarat, India

Natarajan Amaresan
C.G. Bhakta Institute of Biotechnology
Uka Tarsadia University
Surat, Gujarat, India

ISSN 1949-2448 ISSN 1949-2456 (electronic)
Springer Protocols Handbooks
ISBN 978-1-0716-2826-3 ISBN 978-1-0716-2827-0 (eBook)
https://doi.org/10.1007/978-1-0716-2827-0

© The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Science+Business Media, LLC, part of Springer Nature 2023
This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors, and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Humana imprint is published by the registered company Springer Science+Business Media, LLC, part of Springer Nature.
The registered company address is: 1 New York Plaza, New York, NY 10004, U.S.A.

Preface

The indiscriminate usage of fertilizers and pesticides not only destroys beneficial microbes in soil but also acts as a serious threat to the environment. The emerging threats by various abiotic and biotic factors, including drastic changes in climatic conditions, put agricultural industry throughout the globe at great risk. The increasing trends of green revolution have led to the development of promising candidates such as endophytic bacteria and fungi for sustainable development in agricultural field. Research reports and articles have listed the role of endophytic microbes in sustainable development in the agricultural field.

In this context, we have made an effort to compile a user-friendly laboratory manual on endophytic microbes. This manual provides the detailed procedures for the isolation and identification of endophytes, various biochemical methods and molecular methods for the identification of endophytes, various traditional methods, and modern methods to prove endophytism, bioactive potentials, and screening of their metabolites in 5 different sections with 29 protocols. The contents provided in the manual may be used to carry out research work from basic laboratories with elementary facilities to high-end laboratories.

We hope that the manual will be highly useful to the research and academic communities, especially young researchers/students. We are thankful to all contributors to this book, who spared their valuable time and cooperated with us for bringing this manual within the specified time period.

Healthy criticism and comments are highly welcome from the readers.

Kalaburagi, Karnataka, India — *A. Sankaranarayanan*
Surat, Gujarat, India — *Natarajan Amaresan*
Surat, Gujarat, India — *Mitesh Kumar Dwivedi*

Contents

Preface . . . . . *v*
Contributors . . . . . *xi*

PART I CULTIVATION METHODS OF BACTERIAL ENDOPHYTES

1 Isolation of Endophytic Bacteria from Leaves, Stems, or Roots 3
Joyce Prisca Bakuwa Njoloma

2 Heat-Treatment Method for Isolation of *Bacillus* spp. from Plant Tissues 7
T. R. Kavitha, C. Suneetha, and T. R. Sunitha

3 Isolation and Detection of Endophytic *Streptomyces* from Actinorhizal *Casuarina* Root Nodules 15
Thirumagal Thirugnanam and Dhanasekaran Dharumadurai

4 Isolation of Endophytic Fungi from Stems, Leaves, or Roots 27
V. Ambikapathy, N. Sengottaian, A. S. Shijila Rani, S. Babu, and A. Anbukumaran

PART II BIOCHEMICAL METHODS FOR IDENTIFICATION OF ENDOPHYTES

5 Detection of Endophytes by Cultivation Method 33
Paula Rodríguez, David Gonzalez, and Sonia Rodríguez Giordano

6 Detection of Endophytes by Visualization Methods 43
Vijayalakshmi Selvakumar, Karnan Muthusamy, Thenmozhi Manivel, Preethi Gopalsamy, Panneerselvam Annamalai, Ramachandran Chelliah, and Deog-Hwan Oh

7 Detection of Endophytes by Immunological Methods 51
Bankapura Mariyappa Ravikumara, Lakshmaiah Manjunatha, Kittan Subathra, Gummeral Narasareddy, Gangadharaiah Jyothi, and Chikkabuddi Prashantha

8 Detection of Endophytes by Electron Microscope 71
Pradeep Kumar, Simran Rani, Sarita, Amita Suneja Dang, and Pooja Suneja

9 Detection of Endophytes by Reactive Oxygen Staining 77
Simran Rani, Pradeep Kumar, Deepika, Amita Suneja Dang, and Pooja Suneja

PART III MOLECULAR METHODS FOR IDENTIFICATION OF ENDOPHYTES

10 Identification of Bacterial Endophytes by 16S rRNA 85
V. Ambikapathy, S. Babu, R. Shanmugapriya, A. Prakash, and A. S. Shijila Rani

11 Identification of Fungal Endophytes by ITS rDNA Technique 89
Pooja Suneja, Pradeep Kumar, Simran Rani, Simran, and Amita Suneja Dang

12 Identification of Fungal Endophytes by 28SrDNA Technique 97
Karnan Muthusamy, Tamilkani Pichai, Vijayalakshmi Selvakumar, Anbukumaran Ananthan, Reshma Devi Ramesh, Leelavathi Lakshmanan, Senthilkumar Govindarajan, Panneerselvam Annamalai, and Ki Choon Choi

13 Detection of Endophytes by Molecular Fingerprinting Techniques. 109
Lakshmaiah Manjunatha, Gummeral Narasareddy, Bankapura Mariyappa Ravikumar, Leela Saisree Uppala, Rishikesh Kumar, Nanjundappa Manjunatha, Manikyanahalli Chandrashekara Keerthi, Raj Kumar Mishra, and Bansa Singh

14 Metagenomics and Pyrosequencing Approach 135
Jean Carlos Vencioneck Dutra and Maria do Carmo Pimentel Batitucci

Part IV Methods to Proof Endophytism

15 Cultivation-Based Studies of Endophytic Fungi in Plants 145
Lizzy A. Mwamburi

16 Microscopy-Based Studies 153
C. Brígido and A. Paço

17 Surrogate Host Test. 169
Harshida A. Gamit and Natarajan Amaresan

18 Hood and Shew Staining 173
Harshida A. Gamit and Natarajan Amaresan

Part V Endophytes for Bioactive Metabolites

19 Screening of Endophytes for Plant Growth-Promoting Metabolites 179
Rinka S. Pramanik, Sapna Chandwani, and Natarajan Amaresan

20 Screening of Endophytes for Biocontrol Properties 189
Shah Rushabh, Sapna Chandwani, and Natarajan Amaresan

21 Screening of Endophytes for Biocatalytic Tools 193
David Gonzalez, Emiliana Botto, Sonia Rodríguez Giordano, and Paula Rodríguez Bonnecarrere

22 Screening of Endophytes for Biosurfactant Production 209
V. Ambikapathy, S. Babu, A. Anbukumaran, and A. S. Shijila Rani

23 Screening of Endophytes for Antibacterial Properties. 213
M. Veerapagu, K. R. Jeya, and A. Sankaranarayanan

24 Screening of Endophytes for Nematicidal Activities 225
Soma Barman, Ratan Chowdhury, and Satya Sundar Bhattacharya

25 Screening of Endophytes for Virucidal Activity 237
L. Manjunatha, G. Narasa Reddy, LeelaSaisree Uppala, B. M. Ravikumara, and R. Ranjini

26 Screening of Endophytes for Fungicidal Activities 245
K. R. Jeya, M. Veerapagu, and A. Sankaranarayanan

27 Screening of Endophytes for Anticancer Compounds 255
Drielly Dayanne Monteiro dos Santos Baliza, Juliana Fonseca Moreira da Silva, Eskálath Morganna Silva Ferreira, Irlon M. Ferreira, Edilene Oliveira da Silva, José Luiz Martins do Nascimento, and Raphael Sanzio Pimenta

Index *269*

Chapter 23

Screening of Endophytes for Antibacterial Properties

M. Veerapagu, K. R. Jeya, and A. Sankaranarayanan

Abstract

Endophytes are microbes that reside inside the tissues of healthy plants with the varied relationship but not producing any disease symptoms including but not limited to bacteria, actinomycetes, mycoplasma, and fungi. Endophytes are ubiquitous with rich biodiversity, which have been found in almost all species of plant. Endophytes of plant are considered as a vital source of natural bioactive compounds that help the host plant to improve defense against pathogens causing disease to plant can be exploited to produce antibiotics in pharmaceutical industries for the treatment of human diseases caused by microbes. Hence techniques to screen endophytes for antibacterial properties by cross-streak method and agar plug diffusion methods are important in search of new natural antibacterial drugs with improved potential.

Key words Plant, Endophyte, Antibiotics, Cross-streak method, Agar plug diffusion method

1 Introduction

Plants are considered to be a vital source of bioactive compounds having medicinal value from ancient times. Many diseases are cured from the extracts of different plant parts which exhibited distinct remedial properties. Amusingly, in recent years, products of therapeutic potential have been proved to be offered from microbes of plant endophytes and have been increased. Most microorganisms that inhabit the plants exhibit positive interactions. A plant can harbor thousands of microorganisms which can be epiphytes or endophytes depending on their colonization in the plant [1].

Endophytes are a diverse group of endosymbionts mostly bacteria including actinomycetes and mycoplasma and fungi which colonizes the internal plant tissues without causing any type of harm to the host plant [2]. Their whole life cycle or part of their life cycle occurs within the plant host. Endophytes could have entered inside the plants principally through the aerial, subaerial, and underground parts of plants. Many endophytes synthesize broad spectrum of bioactive metabolites [3]. Biopotential metabolites of plant endophytes have inherent applications in agronomy,

A. Sankaranarayanan et al. (eds.), *Endophytic Microbes: Isolation, Identification, and Bioactive Potentials*, Springer Protocols Handbooks, https://doi.org/10.1007/978-1-0716-2827-0_23,
© The Author(s), under exclusive license to Springer Science+Business Media, LLC, part of Springer Nature 2023

beauty aids, pharmaceutics, food production, and processing technology [4]. Diverse bioactive metabolites from endophytic plant microbes displayed germicidal, antioxidative, antitumoral, insecticidal, antiparasitics, and immunosuppressive properties [5]. Hence the products from microbial endophytes of plants exerted considerable use in a large number of industries.

Demand for new drugs or secondary metabolites is increasing by virtue of the development of resistance of pathogens to antibiotics. Endophytes could be a promising resource for the discovery of new bioactive compounds with possible medicinal properties. Endophytic bacteria, actinomycetes, and fungi appear to be one of the promising sources of valuable antibacterial metabolites [6]. Many endophytes have been identified to exhibit antibacterial activity and some of which cited in recent literatures are listed in Table 1.

Altogether 15 bacterial endophytes from leaves of *Tamarindus indica* revealed antagonistic toward *B. cereus*, *S. aureus,* and *E. coli* [22]. Endophytic actinomycetes *Aeromicrobium, Actinomadura*, *Microbacterium*, *Microbispora*, *Micrococcus*, *Sphaerisporangium*, *Streptomyces*, and *Williamsia* isolated from medicinal plant *Vochysia divergens* disclosed in opposition to *S. aureus* resistance to methicillin [23]. Endophytic fungi *Syncephalastrum rasemosum*, *Syncephalastrum racemosums328* were isolated from mature healthy leaves and bark of medicinal plant *Saraca asoca* showed antibacterial activity against three pathogenic bacteria, i.e., *Streptococcus mutans*, *L. acidophilus,* and *E. faecalis* [24].

Endophytes isolated from leaves, stems, and roots of the plant were screened for their antibacterial properties. There are different methods available while cross-streak method and agar plug diffusion methods are simple, efficient, and most widely used for preliminary qualitative screening of antibacterial activities of endophytes. The antimicrobial activity of seven endophytic bacterial isolates from *Moringa peregrina* was screened against 11 human pathogens and were screened qualitatively by the cross-streak method [25]. Syed et al. [26] evaluated the antibacterial activity of three isolates from the root of *Capsicum annum* against *Staphylococcus aureus*, *E. coli*, *Pseudomonas* sp., *P.vulgaris*, and *Klebsiella* sp., through the cross-streak method.

Agar plug diffusion method was used for the preliminary screening of antibacterial properties of 12 endophytic fungal isolates from the bark of *Cinnamomum mercadoi* antagonistic to *S. aureus*, *B. cereus*, *E. coli*, and *P. aeruginosa* [27]. Endophytic fungi, a total of sixty five isolates from leaves of *Indigofera suffruticosa* were preliminarily screened for antibacterial activity by agar plug method against *S. aureus*, *B. subtilis*, *E. coli*, *K. pneumoniae,* and *P. aeruginosa* [28]. Several literatures are available for the screening of antibacterial property of endophytes by cross-streak method [29, 30] and agar plug diffusion method [31, 32] (Table 1).

Table 1
Antibacterial properties of endophytes

Endophyte	Host plant	Activity against bacterium	Reference
Alternaria alternata	*Picorrhiza kurroa*	*B. subtilis, S. aureus.*	Chandra et al. [7]
Raffaele sp.	*Cocos nucifera (L.)*	*E. coli*, *B. subtilis*, *S. aureus*	Fuego et al. [8]
Bacillus amyloliquefaciens	*Salicornia brachiata*	*S. aureus* and *Xanthomonas campestri*	Singh et al. [9]
*Diaporthe*sp	*Ligustrum obtusifolium.*	*S.aureus,E.coli,Salmonella enterica*, *B.cereus*, *Listeria monocytogenes*	Saravanakumar et al. [10]
Pseudomonas putida and *Metarhizium anisopliae*	*Oryza sativa* L	*Xanthomonas oryzae* up. *oryzae*	Saikia & Bora et al. [11]
Fusarium sp.	*Falcataria moluccana*	*B. subtilis, P. aeruginosa, E. coli*	Rumidatul et al. [12]
Aspergillus tubenginses	*Hyoscyamus muticus*	*P. aeruginosa, S. aureus, E.coli, Candida albicans*, and *B. subtilis*	Elkhouly et al. [13]
Bacillus amyloliquefaciens	*Drosera burmannii*	*B. cereus, S. haemolyticus,S.epidermidis,P. aeruginosa, K. pneumonia*	Chaudhuri et al. [14]
P. chrysogenum	*Artemisia sieberi*	*A. baumannii*, *E. aerogenes*, *E. coli*, *K. oxytoca*, *K. pneumoniae*, *P. aeruginosa*, *Streptococcus agalactiae*, *S. epidermis*, *S. aureus*	Ababutain et al. [15]
Streptomyces armeniacus	*Thymus roseus*	*S.aureus,Bacillus cereus*, *Salmonella enteritidis*	Musa et al. [16]
Bacillus subtilis	*Pseudobrickellia brasiliensis*	*E. coli*, *P. aeruginoa*, *S. aureus*	Cardoso et al. [17]
Burkholderia sp. WYAT7	*Artemisia nilagirica* (Clarke) Pamp.	*P. aeruginosa* (MTCC 2453), *P. aeruginosa*(MTCC 1610), *Salmonella paratyphi*, *B. subtilis*	Ashitha et al. [18]
Bacillus velezensis	*Tamarindus indica* L.	*P. aeruginosa*, *N. gonorrhoeae*	Chigurupati et al. [19]
Streptomyces sp.	*Neesia altissima*	*Bacillus cereus* (ATCC 10876), *taphylococcus aureus* (ATCC 25923)	Pratiwi et al. [20]
Aspergillus cejpii	*Nelumbo nucifera*	Methicillin-resistant *Staphylococcus aureus* DMST20651 (MRSA)	Techaoei et al. [21]

2 Materials

2.1 Screening of Endophytes for Antibacterial Property by Cross-Streak Method (Fig. 1)

- 70% v/v ethanol.
- Double distilled water.
- Erlenmeyer flask.
- Measuring cylinder.
- pH meter.
- Nutrient agar medium.
- Petri plates.
- Microbial culture: Pure culture of endophytic bacteria, actinomycetes, and target bacteria.
- Bunsen burner.
- Inoculation loop.
- Digital balance.

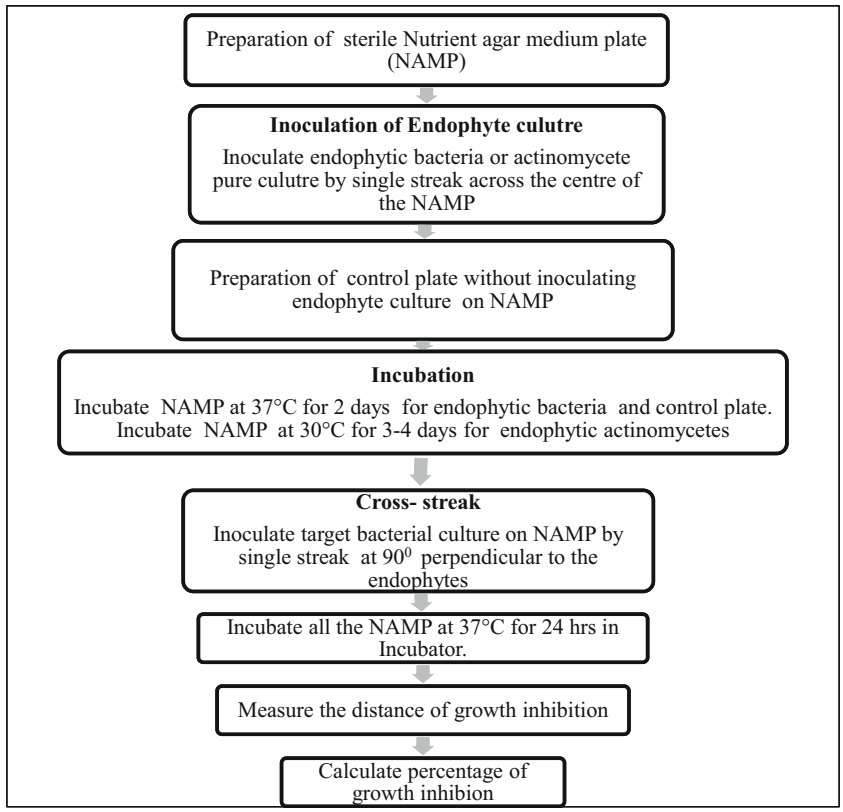


Fig. 1 Screening of endophytes for antibacterial properties by cross-streak method

- Hot air oven.
- Water bath.
- Autoclave.
- Laminar airflow hood.
- Incubator.
- Non-absorbent cotton.

2.2 Screening of Endophytes for Antibacterial Property Agar Plug Diffusion Method

- 70% v/v ethanol.
- Double distilled water.
- Erlenmeyer flask.
- Measuring cylinder.
- pH meter.
- Potato dextrose agar (PDA).
- Yeast malt agar (YMA).
- Muller Hinton agar (MHA).
- Microbial culture: Pure culture of endophytic fungus, Actinomycetes, and target bacteria.
- 0.5McFarland standard (Himedia).
- Antibiotic zone scale (Himedia).
- Petri plate 100 x 15 mm.
- Bunsen burner.
- Inoculation loop.
- Cork borer.
- Forceps.
- Knife.
- Scalpel blade.
- Digital balance.
- Hot air oven.
- Water bath.
- Autoclave.
- Laminar airflow hood.
- Incubator.
- Sterile Cotton swab.

3 Methodology

3.1 Screening of Endophytes for Antibacterial Property by Cross-Streak Method

3.1.1 Inoculation of Endophyte Culture by Single Streak

1. Prepare the nutrient agar medium and sterilize it [33].
2. Take the pure culture of endophytic bacteria or actinomycetes from the nutrient agar slant aseptically.
3. Inoculate the endophytes across the center of the nutrient agar medium plate by single streak [34].
4. Prepare the control plate without streaking endophytic culture on the nutrient agar medium.
5. Incubate the endophytic bacteria at 37 °C for 2 days and at 30 °C for 3–4 days for endophytic actinomycetes.

3.1.2 Inoculation of Target Bacterial Culture by Cross-Streak

1. Inoculate the target bacteria by single streak at an angle of 90° perpendicular to the endophyte without touching the line of endophytes including control plates.
2. Incubate the plates at 37 °C for 24 h in an incubator.
3. Measure the distance of inhibition growth after incubation (Fig. 3).
4. Calculate the percentage of inhibition by the following formula [35] (Table 2):

$$\text{Growth Inhibition}\% = \frac{\text{length of target bacterial streak–length of target bacterial growth} \times 100}{\text{length of target bacterial streak}}$$

5. Note the percentage of inhibition as

   Strong inhibition [+4, ≥ 90%]

   Good inhibition [+3, ≥ 75%]

   Moderate inhibition [+ 2, ≥ 50%]

   Weak inhibition [+, ≥ 15%]

   No inhibition [−]

Table 2
Percentage of growth inhibition of target bacteria by endophyte using the cross-streak method

Target bacteria	Length of streak (mm) A	Length of growth (mm) B	Growth inhibition % (A-B)/ AX100
Target bacteria 1			
Target bacteria 2			
Target bacteria 3			

3.2 Screening of Endophytes for Antibacterial Property Agar Plug Diffusion Method (Fig. 2)

3.2.1 Preparation of Agar Plug

1. Select the well-isolated fungal endophytes or actinomycetes colony from the growing edge with the aid of inoculation loop.
2. Spot inoculate fungal colony at the center of the PDA agar medium or actinomycetes on yeast malt agar medium (YMA).
3. Incubate the PDA plates for 21 days at 25 ± 2 °C [36] or YMA at 28 ± 2 °C for 7–10 days [37].
4. With the help of sterile cork borer cut an agar plug of 6 mm diameter from the actively growing margin of endophyte [38].

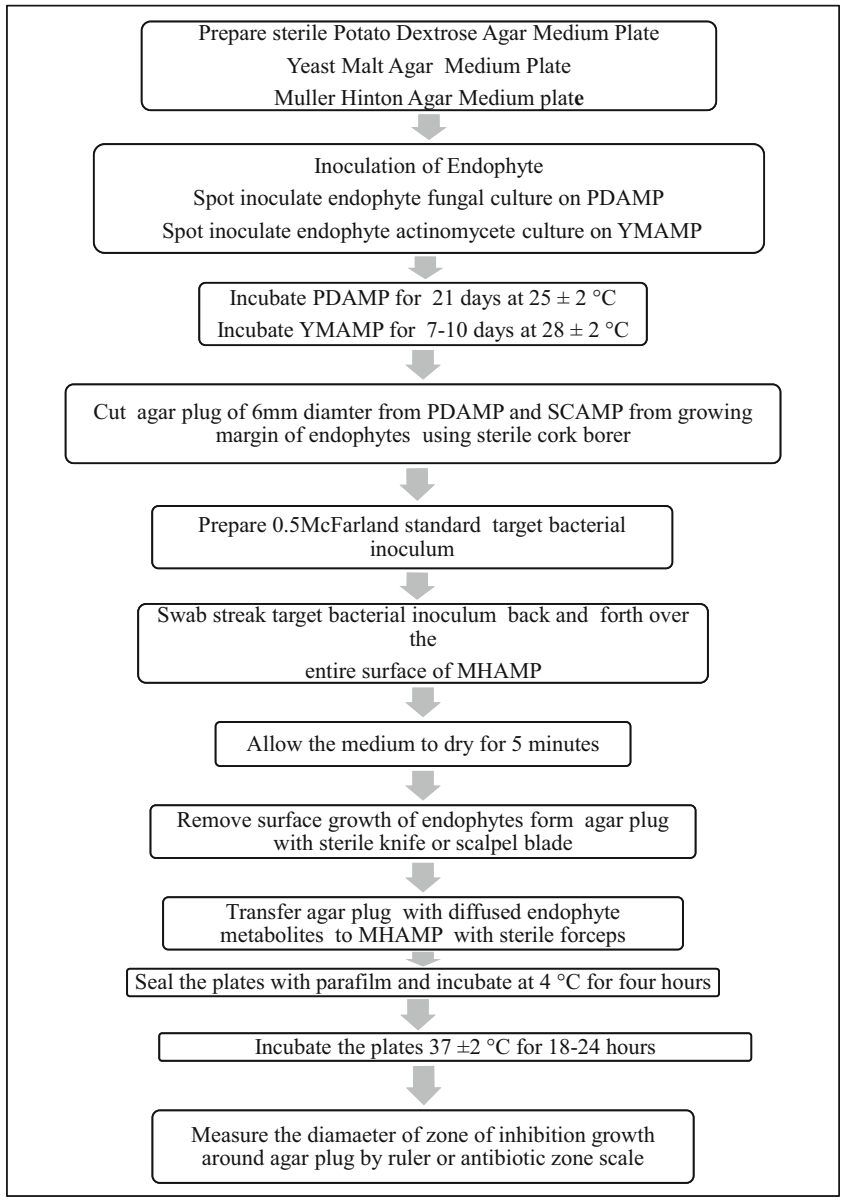


Fig. 2 Screening of endophytes for antibacterial properties by agar plug diffusion method

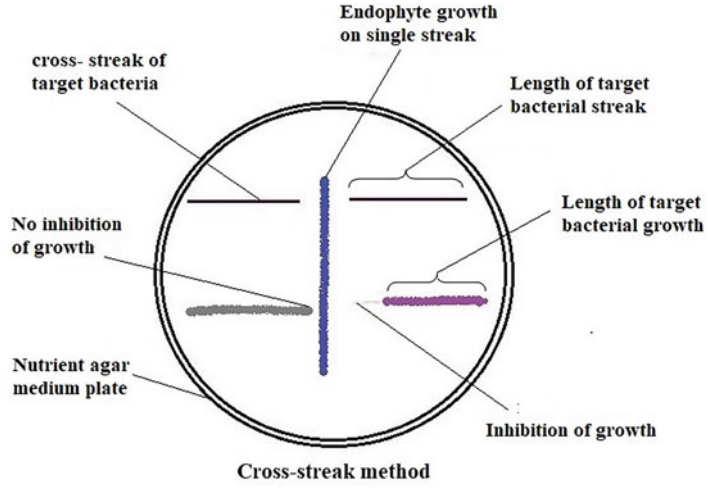


Fig. 3 Diagrammatic representation of cross-streak method for screening of antibacterial property of endophytes

3.2.2 Preparation of 0.5McFarland Standard Target Bacterial Inoculum

1. Take four or five colonies of target bacteria from the pure culture of the organism (not more than 48 h old except slow-growing organisms).
2. Transfer the bacterial colonies into 2 mL of sterile saline and gently vortex it.
3. Add more colonies or dilute with sterile suspension to make up the turbidity of bacterial suspension as per 0.5McFarland standard [39].
4. Use this inoculum suspension (1–2 × 10^8 CFU/mL) within 15 min of preparation.

3.2.3 Inoculation of MHA Plate

1. Inoculate the bacteria on MHA medium and leave the plates for 5–15 mins.

3.2.4 Transfer of Agar Plug

1. Remove the growth of endophyte from the surface of agar plug with a sterile knife or scalpel blade carefully without damaging agar plug [40].
2. Hold the agar plug containing only diffused metabolites of endophytes with the help of sterile forceps.
3. Retain the agar plug in the middle of the MHA plates pre-seeded with target bacteria.
4. Seal the plates with parafilm.
5. Keep the plate in an ice box at 4 °C for 4 h for metabolite diffusion [41].

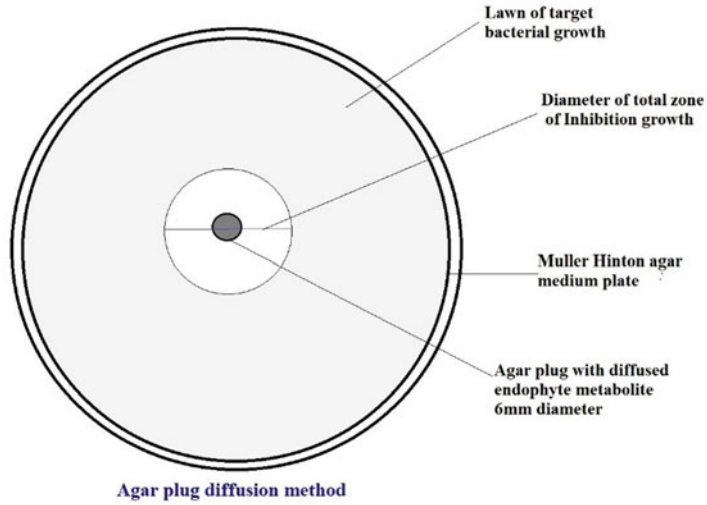


Fig. 4 Diagrammatic representation of agar plug diffusion method for screening of endophytes for antibacterial property

Table 3
Zone of growth inhibition of target bacteria by endophyte using agar plug diffusion method

Target bacteria	Total zone of inhibition growth diameter (mm) A	Agar plug diameter (mm) B	Zone of inhibition growth (mm) A-B
Target bacteria 1			
Target bacteria 2			
Target bacteria 3			

6. Incubate the MHA plates at 37 ± 2 °C for 18–24 h in an incubator.
7. Measure the zone of inhibition around the agar plug following incubation (Fig. 4).
8. Calculate zone of inhibition growth by decreasing the diameter of the agar plug from the total zone of inhibition growth [42] (Table 3).

Zone of inhibition growth
= Diameter of total zone of Inhibition growth (mm)–Diameter of agar plug (6 mm).

4 Observations

4.1 Screening of Endophytes for Antibacterial Properties by Cross-Streak Method

4.2 Screening of Endophytes for Antibacterial Properties by Agar Plug Diffusion Method

References

1. Gouda S, Das G, Sen SK, Shin HS, Patra JK (2016) Endophytes: a treasure house of bioactive compounds of medicinal importance. Front Microbiol 7:1538
2. Tadych M, White JF (2019) Endophytic microbes, encyclopedia of microbiology, 4th edn. Academic Press, pp 123–136
3. Mohana NC, Rakshith D, Ramesha KP, Nuthan BR, Harini BP, Satish S (2021) TLC directed isolation and in silico analysis of antimicrobial metabolite from *Nigrospora sphaerica* inhabiting *Croton bonplandianus* Baill. South Afr J Bot 139:106–113
4. Nazir A, Rahman HA (2018) Secrets of plants: endophytes. Int J Plant Biol 9(1). https://doi.org/10.4081/pb.2018.7810
5. Singh A, Singh DK, Kharwar RN, White JF, Gond SK (2021) Fungal endophytes as efficient sources of plant-derived bioactive compounds and their prospective applications in natural product drug discovery: insights, avenues, and challenges. Microorganisms 9(1): 197
6. Sharma D, Pramanik A, Agrawal PK (2016) Evaluation of bioactive secondary metabolites from endophytic fungus *Pestalotiopsis* neglecta BAB-5510 isolated from leaves of *Cupressus torulosa* D. Don. 3 Biotech 6:210
7. Chandra H, Kumari P, Prasad R, Gupta SC, Yadav S (2021) Antioxidant and antimicrobial activity displayed by a fungal endophyte *Alternaria alternata isolated* from *Picrorhiza kurroa* from Garhwal Himalayas, India. Biocatal Agric Biotechnol:101955
8. Fuego B, Romano K, Pinlac CLirio G (2021) Evaluation of the antimicrobial activity of endophytic fungus isolated from *Cocos nucifera* (L.) cotyledon against medically-important pathogens. J Biosci Med 9:86–97
9. Singh S, Ghadge VA, Kumar P, Mathew DE, Dhimmar A, Sahastrabudhe H, Nalli Y, Rathod MR, Shinde PB (2021) Biodiversity and antimicrobial potential of bacterial endophytes from halophyte *Salicornia brachiate*. Antonie Van Leeuwenhoek:1–18. https://doi.org/10.1007/s10482-021-01544-4
10. Saravanakumar K, Sriram B, Sathiyaseelan A, Hu X, Mariadoss AVA, MubarakAli D, Wang MH (2021) Molecular identification, volatile metabolites profiling, and bioactivities of an indigenous endophytic fungus (*Diaporthe* sp.). Process Biochem 102:72–81
11. Saikia K, Bora LC (2021) Exploring actinomycetes and endophytes of rice ecosystem for induction of disease resistance against bacterial blight of rice. Eur J Plant Pathol 159(1):67–79
12. Rumidatul A, Rahmawati N, Sunarya S (2021) Production of secondary metabolites and its antibacterial and antioxidant activity during the growth period of endophytic fungi isolated from gall rust *Sengon*. Plants Pharma J 13(2): 325–331

13. Elkhouly HI, Hamed AA, El Hosainy AM, Ghareeb MA, Sidkey NM (2021) Bioactive secondary metabolite from endophytic *Aspergillus tubenginses* ASH4 isolated from *Hyoscyamus muticus*: antimicrobial, antibiofilm, antioxidant and anticancer activity. Pharmacog J 13(2):434–442
14. Chaudhuri M, Paul AK, Arundhati P (2021) Isolation of potential antimicrobial metabolite from endophytic *Bacillus amyloliquefaciens*DL06 of carnivorous plant *Drosera burmannii* VAHL. Asian J Pharm Clin Res 14(1):163–170
15. Ababutain IM, Aldosary SK, Aljuraifani AA, Alghamdi AI, Alabdalall AH, Al-Khaldi EM, Borgio JF (2021) Identification and antibacterial characterization of endophytic fungi from *Artemisia sieberi*. Int J Microbiol:Article ID 6651020. https://doi.org/10.1155/2021/6651020
16. Musa Z, Ma J, Egamberdieva D, Abdelshafy Mohamad OA, Abaydulla G, Liu Y, Li WJ, Li L (2020) Diversity and antimicrobial potential of cultivable endophytic actinobacteria associated with the medicinal plant *Thymus roseus*. Front Microbiol 11:191
17. Cardoso VM, Campos FF, Santos ARO, Ottoni MHF, Rosa CA, Almeida VG, Grael CFF (2020) Biotechnological applications of the medicinal plant *Pseudobrickellia brasiliensis* and its isolated endophytic bacteria. J Appl Microbiol 129(4):926–934
18. Ashitha A, Radhakrishnan EK, Mathew J (2020) Characterization of biosurfactant produced by the endophyte *Burkholderia* sp. WYAT7 and evaluation of its antibacterial and antibiofilm potentials. J Biotechnol 313:1–10
19. Chigurupati S, Vijayabalan S, Selvarajan KK, Aldubayan M, Alhowail A, Mani V, Das S (2020) Antimicrobial exploration between counterpart endosymbiont and host plant (*Tamarindus indica* Linn.). Curr Pharm Biotechnol 21(5):384–389
20. Pratiwi RH, Hidayat I, Hanafi M, Mangunwardoyo W (2020) Isolation and structure elucidation of phenazine derivative from *Streptomyces* sp. strain UICC B-92 isolated from *Neesia altissima* (Malvaceae). Iran J Microbiol 12(2):127–137
21. Techaoei S, Jirayuthcharoenkul C, Jarmkom K, Dumrongphuttidecha T, Khobjai W (2020) Chemical evaluation and antibacterial activity of novel bioactive compounds from endophytic fungi in *Nelumbo nucifera*. Saudi J Biol Sci 27(11):2883–2889
22. Sawarkar A, Sharma RK, Gautam V, Shraman K, Jain S (2021) Antibacterial activity of endophytic bacteria from leaves of *Tamarindus indica*. Pharma Innov J 10(2):472–475
23. Gos FM, Savi DC, Shaaban KA, Thorson JS, Aluizio R, Possiede YM, Glienke C (2017) Antibacterial activity of endophytic actinomycetes isolated from the medicinal plant *Vochysia divergens* (Pantanal, Brazil). Front Microbiol 8:1642
24. Tilwari A, Dixit P (2018) Isolation and screening of endophytic fungus from medicinal plant *Saraca asoca* for antibacterial activity. J Pharmacogn Phytother. SP2: 351–354
25. Aljuraifani A, Aldosary S, Ababutain I (2019) In vitro antimicrobial activity of endophytes, isolated from *Moringa peregrina* growing in eastern region of Saudi Arabia. Natl Acad Sci Lett 42(1):75–80
26. Syed CS, Mounika PPN, Mounika Y, Kumar SS, Bai VT, Audipudi AV (2017) Evaluation of antimicrobial and antibiotic sensitivity of chilli root endophytic bacteria for eco-friendly biofertilizer. Int J Curr Microbiol App Sci 5:45–53
27. Marcellano JP, Collanto AS, Fuentes RG (2017) Antibacterial activity of endophytic fungi isolated from the bark of *Cinnamomum mercadoi*. Pharm J 9(3):405–409
28. Santos IPD, Silva LCND, Silva MVD, Araújo JMD, Cavalcanti MDS, Lima VLDM (2015) Antibacterial activity of endophytic fungi from leaves of *Indigofera suffruticosa* Miller (Fabaceae). Front Microbiol 6:350
29. Chandrakar S, Gupta AK (2017) Antibiotic potential of endophytic actinomycetes of medicinal herbs against human pathogenic bacteria. Proc Natl Acad Sci India B Biol Sci 87(3):905–915
30. Shukla S, Naik G, Mishra SK (2021) Potential antimicrobial activity of bacterial endophytes isolated from *Flacourtia jangomas* (Lour.) Raeusch, a less explored medicinal plant. J Microbiol Biotechnol Food Sci:473–477
31. Muazzam KAAR, Taufig MMJ, Darah I (2015) Isolation and screening of antibacterial activity of endophytic fungi isolates from *Ocimum citriodorum* Vis. leaves. Aust J Basic Appl Sci 9(28):155–161
32. Sadrati N, Zerroug A, Demirel R, Bakli S, Harzallah D (2020) Antimicrobial activity of secondary metabolites produced by *Aspergillus neobridgeri* isolated from *Pistacia lentiscus* against multi-drug resistant bacteria. Bangladesh J Pharmacol 15(3):82–95
33. AhmedZ AS, Alauddin S, Mohiuddin SG, Javed A, Ahmed R, Bitar AN, Sheikh Ghadzi SM (2020) In vitro cytotoxic and antimicrobial activities of *Erythrina suberosa* (Roxb) bark. J Pharm Bioallied Sci 12(2):210–216

34. Mukherjee A, Das R, Pal A, Paul AK (2017) Antibacterial activity of *endophytic Bacillus safensis*isolated from *Ophioglossum reticulatum* L. Microbiol Res J Int 18(5):1–12
35. Kampapongsa D, Kaewkla O (2016) Biodiversity of endophytic actinobacteria from jasmine rice (*Oryza sativa* L. KDML 105) grown in Roi-Et Province, Thailand and their antimicrobial activity against rice pathogens. Ann Microbiol 66(2):587–595
36. Ramesha KP, Mohana NC, Nuthan BR, Rakshith D, Satish S (2020) Antimicrobial metabolite profiling of *Nigrospora sphaerica* from *Adiantum philippense* L. J Gene Eng Biotechnol 18(1):1–9
37. Radhakrishnan M, Vijayalakshmi G, Gopikrishnan V, Jerrine J (2016) Bioactive potential of actinobacteria isolated from certain understudied regions in. India J Appl Pharm Sci 6(08):151–155
38. Mahadevamurthy M, Puttaswamy H, Channappa TM, Sidappa M, Madegowda P, Chikkamanchegowda JS, Nagaraj AK (2016) Antibacterial potential of fungal endophytes isolated from *Boerhaavia diffusa* L. J Appl Pharm Sci 6:216–221
39. Debalke D, Birhan M, Kinubeh A, Yayeh M (2018) Assessments of antibacterial effects of aqueous-ethanolic extracts of *Sida rhombifolia's* aerial part. Sci World J. Article ID 8429809. https://doi.org/10.1155/2018/8429809
40. Uma V, Arunadevi S, Elizabeth JP, Vidhya A (2017) Bioprospecting of actinobacteria from Senganatham Hill Anunexplored ecosystem. Ind J Appl Microbiol 20(1):31–41
41. Manikkam R, Ganesan V, Kaari M, Venugopal G, Arumugam S, Joseph J (2021) Antibacterial efficacy of *Streptomyces maritimus* SACC-E6 against carbapenem-resistant *Klebsiella pneumoniae* ATCC BAA-1705. J Appl Pharm Sci 11(01):089–094
42. Habtom S, Gebrehiwot S (2019) In-vitro antimicrobial activities of crude extracts of *Vernonia amygdalina* and *Croton macrostachyus* against some bacterial and fungal test pathogens. J Phytopharmacol 8(2):57–62

Springer Protocols

A. Sankaranarayanan
Natarajan Amaresan
Mitesh Kumar Dwivedi *Editors*

Endophytic Microbes: Isolation, Identification, and Bioactive Potentials

Springer

SPRINGER PROTOCOLS HANDBOOKS

For further volumes:
http://www.springer.com/series/8623

Springer Protocols Handbooks collects a diverse range of step-by-step laboratory methods and protocols from across the life and biomedical sciences. Each protocol is provided in the Springer Protocol format: readily-reproducible in a step-by-step fashion. Each protocol opens with an introductory overview, a list of the materials and reagents needed to complete the experiment, and is followed by a detailed procedure supported by a helpful notes section offering tips and tricks of the trade as well as troubleshooting advice. With a focus on large comprehensive protocol collections and an international authorship, *Springer Protocols Handbooks* are a valuable addition to the laboratory.

Endophytic Microbes: Isolation, Identification, and Bioactive Potentials

Edited by

A. Sankaranarayanan

Department of Life Sciences, Sri Sathya Sai University for Human Excellence, Navanihal, Kamalapura, Kalaburagi, Karnataka, India

Natarajan Amaresan and Mitesh Kumar Dwivedi

C.G. Bhakta Institute of Biotechnology, Uka Tarsadia University, Surat, Gujarat, India

Humana Press

Editors
A. Sankaranarayanan
Department of Life Sciences
Sri Sathya Sai University for Human Excellence
Navanihal, Kamalapura
Kalaburagi, Karnataka, India

Mitesh Kumar Dwivedi
C.G. Bhakta Institute of Biotechnology
Uka Tarsadia University
Surat, Gujarat, India

Natarajan Amaresan
C.G. Bhakta Institute of Biotechnology
Uka Tarsadia University
Surat, Gujarat, India

ISSN 1949-2448 ISSN 1949-2456 (electronic)
Springer Protocols Handbooks
ISBN 978-1-0716-2826-3 ISBN 978-1-0716-2827-0 (eBook)
https://doi.org/10.1007/978-1-0716-2827-0

© The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Science+Business Media, LLC, part of Springer Nature 2023
This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors, and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Humana imprint is published by the registered company Springer Science+Business Media, LLC, part of Springer Nature.
The registered company address is: 1 New York Plaza, New York, NY 10004, U.S.A.

Preface

The indiscriminate usage of fertilizers and pesticides not only destroys beneficial microbes in soil but also acts as a serious threat to the environment. The emerging threats by various abiotic and biotic factors, including drastic changes in climatic conditions, put agricultural industry throughout the globe at great risk. The increasing trends of green revolution have led to the development of promising candidates such as endophytic bacteria and fungi for sustainable development in agricultural field. Research reports and articles have listed the role of endophytic microbes in sustainable development in the agricultural field.

In this context, we have made an effort to compile a user-friendly laboratory manual on endophytic microbes. This manual provides the detailed procedures for the isolation and identification of endophytes, various biochemical methods and molecular methods for the identification of endophytes, various traditional methods, and modern methods to prove endophytism, bioactive potentials, and screening of their metabolites in 5 different sections with 29 protocols. The contents provided in the manual may be used to carry out research work from basic laboratories with elementary facilities to high-end laboratories.

We hope that the manual will be highly useful to the research and academic communities, especially young researchers/students. We are thankful to all contributors to this book, who spared their valuable time and cooperated with us for bringing this manual within the specified time period.

Healthy criticism and comments are highly welcome from the readers.

Kalaburagi, Karnataka, India — *A. Sankaranarayanan*
Surat, Gujarat, India — *Natarajan Amaresan*
Surat, Gujarat, India — *Mitesh Kumar Dwivedi*

Contents

Preface . . . . . *v*
Contributors . . . . . *xi*

PART I CULTIVATION METHODS OF BACTERIAL ENDOPHYTES

1 Isolation of Endophytic Bacteria from Leaves, Stems, or Roots 3
Joyce Prisca Bakuwa Njoloma

2 Heat-Treatment Method for Isolation of *Bacillus* spp. from Plant Tissues 7
T. R. Kavitha, C. Suneetha, and T. R. Sunitha

3 Isolation and Detection of Endophytic *Streptomyces* from Actinorhizal *Casuarina* Root Nodules 15
Thirumagal Thirugnanam and Dhanasekaran Dharumadurai

4 Isolation of Endophytic Fungi from Stems, Leaves, or Roots 27
V. Ambikapathy, N. Sengottaian, A. S. Shijila Rani, S. Babu, and A. Anbukumaran

PART II BIOCHEMICAL METHODS FOR IDENTIFICATION OF ENDOPHYTES

5 Detection of Endophytes by Cultivation Method 33
Paula Rodríguez, David Gonzalez, and Sonia Rodríguez Giordano

6 Detection of Endophytes by Visualization Methods 43
Vijayalakshmi Selvakumar, Karnan Muthusamy, Thenmozhi Manivel, Preethi Gopalsamy, Panneerselvam Annamalai, Ramachandran Chelliah, and Deog-Hwan Oh

7 Detection of Endophytes by Immunological Methods 51
Bankapura Mariyappa Ravikumara, Lakshmaiah Manjunatha, Kittan Subathra, Gummeral Narasareddy, Gangadharaiah Jyothi, and Chikkabuddi Prashantha

8 Detection of Endophytes by Electron Microscope 71
Pradeep Kumar, Simran Rani, Sarita, Amita Suneja Dang, and Pooja Suneja

9 Detection of Endophytes by Reactive Oxygen Staining 77
Simran Rani, Pradeep Kumar, Deepika, Amita Suneja Dang, and Pooja Suneja

PART III MOLECULAR METHODS FOR IDENTIFICATION OF ENDOPHYTES

10 Identification of Bacterial Endophytes by 16S rRNA 85
V. Ambikapathy, S. Babu, R. Shanmugapriya, A. Prakash, and A. S. Shijila Rani

11 Identification of Fungal Endophytes by ITS rDNA Technique 89
Pooja Suneja, Pradeep Kumar, Simran Rani, Simran, and Amita Suneja Dang

12 Identification of Fungal Endophytes by 28SrDNA Technique 97
Karnan Muthusamy, Tamilkani Pichai, Vijayalakshmi Selvakumar, Anbukumaran Ananthan, Reshma Devi Ramesh, Leelavathi Lakshmanan, Senthilkumar Govindarajan, Panneerselvam Annamalai, and Ki Choon Choi

13 Detection of Endophytes by Molecular Fingerprinting Techniques. 109
Lakshmaiah Manjunatha, Gummeral Narasareddy, Bankapura Mariyappa Ravikumar, Leela Saisree Uppala, Rishikesh Kumar, Nanjundappa Manjunatha, Manikyanahalli Chandrashekara Keerthi, Raj Kumar Mishra, and Bansa Singh

14 Metagenomics and Pyrosequencing Approach 135
Jean Carlos Vencioneck Dutra and Maria do Carmo Pimentel Batitucci

Part IV Methods to Proof Endophytism

15 Cultivation-Based Studies of Endophytic Fungi in Plants 145
Lizzy A. Mwamburi

16 Microscopy-Based Studies 153
C. Brígido and A. Paço

17 Surrogate Host Test. 169
Harshida A. Gamit and Natarajan Amaresan

18 Hood and Shew Staining 173
Harshida A. Gamit and Natarajan Amaresan

Part V Endophytes for Bioactive Metabolites

19 Screening of Endophytes for Plant Growth-Promoting Metabolites 179
Rinka S. Pramanik, Sapna Chandwani, and Natarajan Amaresan

20 Screening of Endophytes for Biocontrol Properties 189
Shah Rushabh, Sapna Chandwani, and Natarajan Amaresan

21 Screening of Endophytes for Biocatalytic Tools 193
David Gonzalez, Emiliana Botto, Sonia Rodríguez Giordano, and Paula Rodríguez Bonnecarrere

22 Screening of Endophytes for Biosurfactant Production 209
V. Ambikapathy, S. Babu, A. Anbukumaran, and A. S. Shijila Rani

23 Screening of Endophytes for Antibacterial Properties. 213
M. Veerapagu, K. R. Jeya, and A. Sankaranarayanan

24 Screening of Endophytes for Nematicidal Activities 225
Soma Barman, Ratan Chowdhury, and Satya Sundar Bhattacharya

25 Screening of Endophytes for Virucidal Activity 237
L. Manjunatha, G. Narasa Reddy, LeelaSaisree Uppala, B. M. Ravikumara, and R. Ranjini

26 Screening of Endophytes for Fungicidal Activities 245
K. R. Jeya, M. Veerapagu, and A. Sankaranarayanan

27 Screening of Endophytes for Anticancer Compounds 255
Drielly Dayanne Monteiro dos Santos Baliza, Juliana Fonseca Moreira da Silva, Eskálath Morganna Silva Ferreira, Irlon M. Ferreira, Edilene Oliveira da Silva, José Luiz Martins do Nascimento, and Raphael Sanzio Pimenta

Index *269*

Chapter 26

Screening of Endophytes for Fungicidal Activities

K. R. Jeya, M. Veerapagu, and A. Sankaranarayanan

Abstract

Fungal diseases pose a significant threat to many plants and animals besides public health. Many fungal pathogens invade plants and affect sustainable food production. However, only a few antifungal antibiotics are currently available for the treatment of fungal diseases. Hence the use of replacement medicines has increased popularly over the past few decades. Endophytes are ample and reliable source of unusual bioactive compounds with antifungal potential for development in medical and agricultural industries. Dual culture method is a significant approach to screen antifungal properties of endophytes in pursuit of contemporary natural drugs with enhanced prospective.

Key words Fungal pathogen, Fungal disease, Antifungal antibiotic, Plant, Endophyte, Dual culture method

1 Introduction

In general, plants are conjoined with variegated microbes. Microorganisms which cause infection of the plant and reside within internal plant tissues usually don't affect plants and produce no or any disease symptoms are often called as endophytes. An uncommon environment for existence and initiation of endophytes is usually afforded almost by the plants. Endophytes are omnipresent with affluent biological variety. They are present in almost all plant species and each plant contains one or more endophytes [1]. Endophyte comprises a diverse range of microbes including bacteria, fungi, and actinomycetes, composed of a multifarious microecosystem [2].

Endophytes help in the adaptation of plants to the environmental stress and increase their tolerance to drought, salinity, and high temperature. They produce several bioactive secondary metabolites and protect plant hosts against predators and resistance to disease-causing pathogens [3–5]. Several endophytes of plant

A. Sankaranarayanan et al. (eds.), *Endophytic Microbes: Isolation, Identification, and Bioactive Potentials*, Springer Protocols Handbooks, https://doi.org/10.1007/978-1-0716-2827-0_26,
© The Author(s), under exclusive license to Springer Science+Business Media, LLC, part of Springer Nature 2023

exhibited activity against pathogenic fungus [6]. Antifungal properties of endophytes in the recent literatures are listed in Tables 1 and 2.

The metabolites of endophytic bacterium *Bacillus amyloliquefaciens* DL06 from *Drosera burmannii* plant leaf exhibited activity against *Alternaria solani*, *Cochliobolus lunatus*, *Rhizoctonia solani*, *Fusarium oxysporum*, *Sclerotium rolfsii,* and *Saccharomyces boulardii* [22]. Endophytic actinomycetes *Streptomyces lydicus* from *Oryza sativa* L. showed strongly antagonistic against rice pathogenic fungi, *Fusarium oxysporum*, *Rhizoctonia solani,* and *Helminthosporium oryzae* [23].

Screening of antifungal properties of endophytes is performed after its isolation from varied parts of plants such as leaves, stems, and roots. Dual culture method is principal and foremost among the other methods widely used for the evaluation of antifungal properties of endophytic isolates. The antifungal activity of two endophytic fungal isolates *Alternaria* sp. from *Lithraeacaustica* and *Aureobasidium* sp. from *Echinopsis chiloensis* against phytopathogenic fungus *Botrytis cinerea* causing graymold disease was screened qualitatively by dual culture method [24]. Khan et al. [25] employed a dual culture method for the evaluation of antifungal activity of endophyte *Bacillus velezensis* from *Lilium leucanthum* against *Botryosphaeria dothidea*, *Fusarium oxysporum*, *Botrytis cinerea,* and *Fusarium fujikuroi*. Many authors investigated the antifungal activity of endophytes by dual culture methods [26–28].

2 Materials

- 70% v/v ethanol.
- Distilled water.
- Conical flask.
- Measuring cylinder.
- Bunsen burner.
- Inoculation loop.
- Digital balance.
- Hot air oven.
- Water bath.
- Hot plate.
- Autoclave.
- Laminar airflow hood.
- Cork borer.
- Forceps.

Table 1
Fungicidal activities of endophytes

Endophytes	Host plant	Activity against fungi	Reference
Bacillus sp.	*Theobroma cacao*	*Moniliophthora roreri, Moniliophthora perniciosa*	Serrano et al. [7]
Bacillus velezensis	*Populusdavidiana* × *P. alba var. pyramidalis (PdPap)*	*Alternaria alternata*	Zhang et al. [8]
*Bacillus*sp, *Enterobacter* sp	Tomato plant	*Botrytis cinerea*	Chaouachi et al. [9]
Aspergillus, *fusarium*	*Sceletium tortuosum*	*Fusarium oxysporum, fusarium graminearum, Colletotrichum gleosporioides. Borytiscinerea*	Sishuba et al. [10]
Trichoderma sp.	*Leucas aspera*, *Pterocarpus santalinus*, *Juniperuslutchuensis*	*Sclerotinia sclerotiorum, Sclerotium rolfsii, fusarium oxysporum*	Rajani et al. [11]
Trichoderma longibrachiatum, T. asperellum, T. atroviride	Soybean (*Glycine max* L.)	*Rhizoctonia solani*	Sallam et al. [12]
Serratia sp.	*Mimosa pudica*	*Fusarium* sp., *Alternaria solani,*	Méndez-Santiago et al. [13]
Streptomyces sp.	*Pinus dabeshanensis*	*Fusarium oxysporum, Rhizoctonia solani, Phytophthora infestan, Candida albicans.*	Peng et al. [14]
Streptomyces polyantibioticus	Thymus roseus	*Alternaria solani, Valsamalicola, Valsamali*	Musa et al. [15]
Streptomyces sp.	*Artemisia herba-alba*	*Botrytis cinerea*	El-Shatoury et al. [16]
Aplosporellajaveedii	*Orychophragmus violaceus*	*Candida albicans*	Gao et al. [17]
Trichoderma atroviride, *Trichoderma koningii*	*Cupressaceae*	*A. niger*, *A. fumigatus*	Erfandoust et al. [18]
Fusarium verticilloides	*Mentha piperita* L.	*A. austroafricanus, A. versicolor, Phomafungicola, A. turbingensis, C. albicans*	Ebrahim et al. [19]

(continued)

Table 1
(continued)

Endophytes	Host plant	Activity against fungi	Reference
Rhizopus oryzae, *fusarium fujikuroi*	*Debregeasia salicifolia*	*Aspergillus flavus*, *aspergillus Niger*	Nisa et al. [20]
Trichoderma longibrachiatum, *Macrophomina phaseolina*	*Helianthus tuberosus*	*Sclerotium rolfsii*	Suebrasri et al. [21]

Table 2
Fungicidal activities of endophytes against target fungus by dual culture method

Endophytes	Radius of target fungal mycelium on control plate (mm) R1	Radius of target fungal mycelium on dual culture plate (mm) R2	Mycelial growth Inhibition % [(R1–R2)/R1] × 100
Fungus			
Actinomycetes			
Bacteria			

- Incubator.
- Digital caliper/Verner Scale.
- Microbial culture: Pure cultures of endophytic bacteria, fungi, actinomycetes, and target fungi.
- Potato Dextrose Agar: (Potato infusion from – 200 gm, Dextrose – 20 g, Agar – 15 g, distilled water – 1000 mL, pH – 5.6 ± 0.2 at 25 °C).
- Yeast Malt Agar: (peptone – 5gm, yeast extract – 3 g, malt extract – 3 g, dextrose – 10 g, Agar – 20 g, distilled water – 1000 mL, pH – 6.2 ± 0.2 at 25 °C).
- Petri plate 90 mm × 15 mm.

3 Methodology

3.1 Preparation of Potato Dextrose Agar Medium Plate (PDAMP)

1. Measure the required quantity of PDA medium according to the manufacturer's recommendation.
2. Suspend it in distilled water in a conical flask.

3. Boil the medium for complete dissolution in a water bath or hot plate, then adjust the pH of the medium to 5.6 ± 0.2.

3.2 Preparation of Yeast Malt Agar Medium Plate (YMAMP)

Prepare yeast malt agar medium plate by following procedures as mentioned in Subheading 3.1.

3.3 Preparation of Endophytic Mycelial Disk (Fungus & Actinomycetes)

1. Inoculate fungal endophyte as spot at the center of PDA agar medium plate PDAMP or actinomycetes on yeast malt agar medium plate YMAMP.
2. Incubate the PDAMP for 21 days at 25 ± 2 °C [29] or YMAMP at 28 ± 2 °C for 7–10 days [30].
3. Prepare mycelial disk of 5mm^2 diameter from actively growing margin of endophytes with the aid of sterile cork borer [31]

3.4 Preparation of Target Fungal Mycelial Disk

Prepare target fungal mycelial disk as mentioned in Subheading 3.3.

3.5 Inoculation of Dual Culture (Figs. 1 and 2)

3.5.1 Inoculation of Target Fungus and Endophytes (Fungus & Actinomycetes)

1. Place the target fungal mycelial disk onto PDAMP approximately 25 mm away on the 90 mm PDAMP edge on one side [32].
2. Hold the endophytic fungal mycelial disk or actinomycetal disk of 5 mm^2 diameter with sterile forceps.
3. Place them 25 mm away from the margin of PDAMP opposite to target fungus.

3.5.2 Inoculation of Endophytic Bacteria

1. Take a single colony of bacterial endophyte from pure culture and make a streak opposite to target fungus at 25 mm away from the margin of PDAMP [33]
2. The distance between the target fungus and endophytes is around 3 cm away from each other

3.6 Incubation

1. Prepare a control plate with target fungal mycelial disk 5 mm^2 diameter and replace endophytes by 5 mm^2 diameter PDA agar plug on PDAMP [34].
2. Incubate all the PDAMP plates at 28 ± 2 °C for 5–7 days [35].
3. At a regular interval observe the growth of target fungus until the colony spreads over the entire surface of PDAMP in control.
4. Measure the radius of target fungal mycelium (mm) on the control (R1) and on the dual culture plate (R2) with aid of vernier caliper [36] or digital caliper [37].

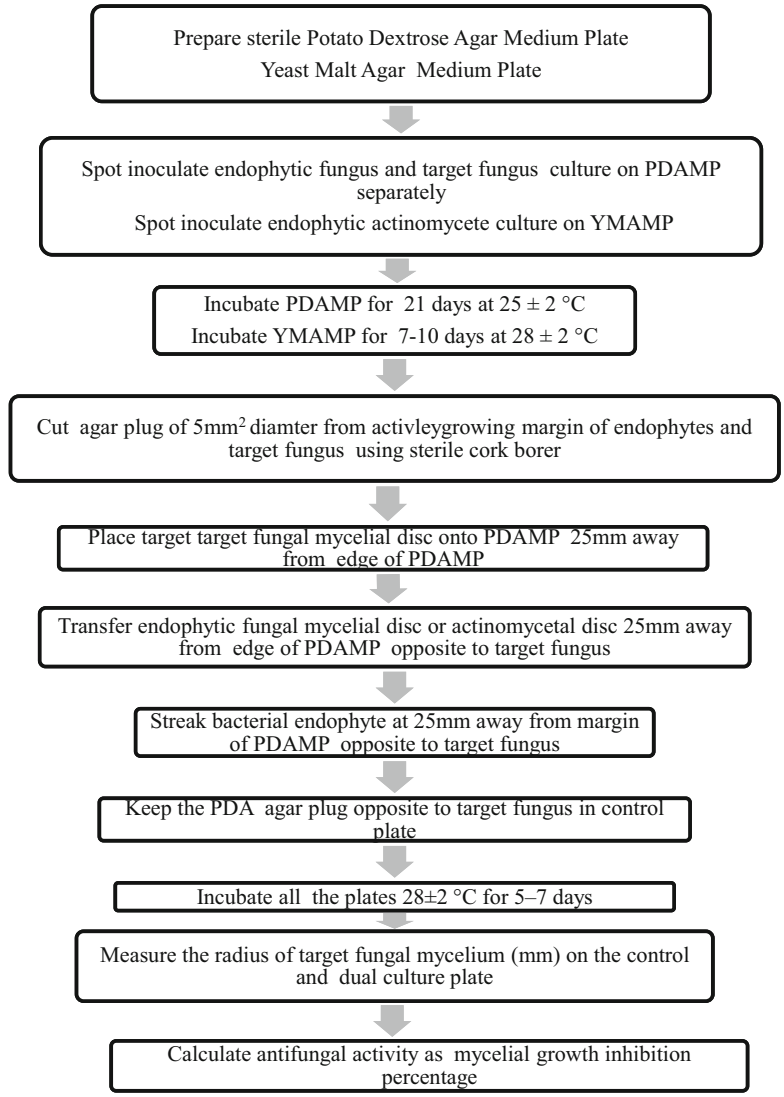


Fig. 1 Various steps for the screening of endophytes for fungicidal activities by dual culture method

5. Calculate the antifungal activity of endophytes as mycelial growth inhibition percentage by the following formula [38]:

$$\mathrm{MGI}\% = [(\mathrm{R1}-\mathrm{R2})/\mathrm{R1}] \times 100$$

4 Observations

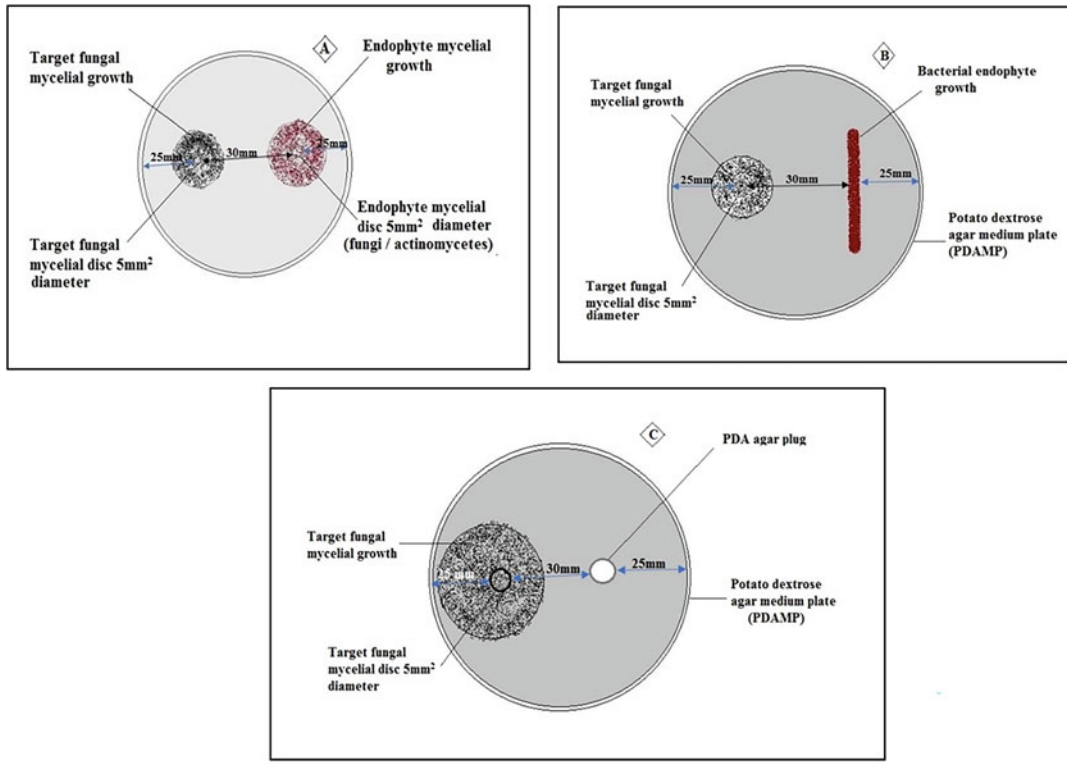


Fig. 2 Diagrammatic representation of screening of endophytes for fungicidal activities by dual culture method. (**a**) Dual culture plate with target fungus and endophytes (fungus/actinomycetes). (**b**) Dual culture plate with target fungus and endophytic bacteria. (**c**) Control plate with target fungus and PDA agar plug

References

1. Kouipou Toghueo RM, Boyom FF (2019) Endophytic fungi from *Terminalia* species: a comprehensive review. J Fungi 5(2):43
2. Golinska P, Wypij M, Agarkar G, Rathod D, Dahm H, Rai M (2015) Endophytic actinobacteria of medicinal plants: diversity and bioactivity. Antonie van Leeuwenhoek 108(2): 267–289
3. Deng Z, Cao L (2017) Fungal endophytes and their interactions with plants in phytoremediation: a review. Chemosphere 168:1100–1106
4. Hassan SE (2017) Plant growth-promoting activities for bacterial and fungal endophytes isolated from medicinal plant of *Teucrium polium* L. J Adv Res 8:687–695
5. Pandey SS, Singh S, Babu CS, Shanker K, Srivastava NK, Kalra A (2016) Endophytes of opium poppy differentially modulate host plant productivity and genes for the biosynthetic pathway of benzylisoquinoline alkaloids. Planta 243:1097–1114
6. Alice FSH, David EW, Charles LC, Camilea RC, Zhiqiang P, Rita MM, Victor LM, Luiz HR (2015) Diversity and antifungal activity of the endophytic fungi associated with the native medicinal cactus *Opuntia humifusa* (*Cactaceae*) from the United States. Microbiol Res 175:67–77
7. Serrano L, Moreno AS, Castillo DSD, Bonilla J, Romero CA, Galarza LL, Coronel–León JR (2021) Biosurfactants synthesized by endophytic *Bacillus* strains as control of *Moniliophthoraperniciosa* and *Moniliophthororaroreri*. Scientia Agricola 78:e20200172
8. Zhang P, Diao J, Xie G, Ma L, Wang L (2021) A complete genome sequence of the wood stem endophyte *Bacillus velezensis* BY6 strain possessing plant growth-promoting and antifungal activities. BioMed Res Int 3904120
9. Chaouachi M, Marzouk T, Jallouli S, Elkahoui S, Gentzbittel L, Ben C, Djébali N (2021) Activity assessment of tomato

endophytic bacteria bioactive compounds for the postharvest biocontrol of *Botrytis cinerea*. Postharvest Biol Technol 172:111389

10. Sishuba A, Leboko J, Ateba CN, Manganyi MC (2021) First report: diversity of endophytic fungi possessing antifungal activity isolated from native Kougoed (*Sceletiumtortuosum* L.). Mycobiology 49(1):89–94
11. Rajani P, Rajasekaran C, Vasanthakumari MM, Olsson SB, Ravikanth G, Shaanker RU (2021) Inhibition of plant pathogenic fungi by endophytic *Trichoderma*sp. through mycoparasitism and volatile organic compounds. Microbiol Res 242:126595
12. SallamN AEF, Seleim MA, Bagy HMK (2021) Endophytic fungi associated with soybean plants and their antagonistic activity against *Rhizoctonia solani*. Egypt J Biol Pest Control 31(1):1–9
13. Méndez-Santiago EW, Gómez-Rodríguez O, Sánchez-Cruz R, Folch-Mallol JL, Hernández-Velázquez VM, Villar-Luna E, Wong-Villarreal A (2021) *Serratia* sp., an endophyte of *Mimosa pudica* nodules with nematicidal, antifungal activity and growth-promoting characteristics. Arch Microbiol 203(2): 549–559
14. PengC AD, Ding WX, Zhu YX, Ye L, Li J (2020) Fungichromin production by *Streptomyces*sp.WP-1,an endophyte from *Pinus dabeshanensis*, and its antifungal activity against *Fusarium oxysporum*. Appl Microbiol Biotechnol 104(24):10437–10449
15. Musa Z, Ma J, Egamberdieva D, Mohamad OAA, Abaydulla G, Liu Y, Li L (2020) Diversity and antimicrobial potential of cultivable endophytic actinobacteria associated with the medicinal plant *Thymus roseus*. Front Microbiol 11:191
16. El-Shatoury SA, Ameen F, Moussa H, Wahid OA, Dewedar A, AlNadhari S (2020) Biocontrol of chocolate spot disease (*Botrytis cinerea*) in faba bean using endophytic actinomycetes *Streptomyces*: a field study to compare application techniques. Peer J 8:e8582
17. Gao Y, Wang L, Kalscheuer R, Liu Z, Proksch P (2020) Antifungal polyketide derivatives from the endophytic fungus *Aplosporellajaveedii*. Bioorg Med Chem 28(10):115456
18. Erfandoust R, Habibipour R, Soltani J (2020) Antifungal activity of endophytic fungi from *Cupressaceae* against human pathogenic *aspergillus fumigatus* and *aspergillus Niger*. Journal de Mycologie Médicale 30(3):100987
19. Ebrahim W, Özkaya FC, Ebada SS (2020) Antifungal metabolites from endophytic fungus *fusarium verticillioides* strain WF18. S Afr J Bot 133:40–44
20. Nisa S, Khan N, Shah W, Sabir M, Khan W et al (2020) Identification and bioactivities of two endophytic fungi *fusarium fujikuroi* and *aspergillus tubingensis* from foliar parts of *Debregeasiasalicifolia*. Arab J Sci Eng 45:4477–4487
21. Suebrasri T, Somteds A, Harada H, Kanokmedhakul S, Jogloy S, Ekprasert J, Boonlue S (2020) Novel endophytic fungi with fungicidal metabolites suppress sclerotium disease. Rhizosphere 16:100250
22. Chaudhuri M, Paul AK, Pal A (2021) Isolation of potential antimicrobial metabolite from endophytic *bacillus amyloliquefaciens*DL06 of carnivorous plant *Droseraburmannii*vahl. Asian J Pharm Clin Res 14(1):163–170
23. Mingma R, Duangmal K (2018) Characterization, antifungal activity and plant growth promoting potential of endophytic actinomycetes isolated from Rice (*Oryza sativa* L.). Chiang Mai J Sci 45(7):2652–2665
24. Vidal A, Parada R, Mendoza L, Cotoras M (2020) Endophytic fungi isolated from plants growing in central Andean Precordillera of Chile with antifungal activity against *Botrytis cinerea*. J Fungi 6(3):149
25. Khan MS, Gao J, Chen X, Zhang M, Yang F, Du Y, Zhang X (2020) The endophytic bacteria *bacillus velezensis* Lle-9, isolated from *Lilium leucanthum*, harborsantifungal activity and plant growth-promoting effects. J Microbiol Biotechnol 30(5):668–680
26. Ali A, Junda M, Karim H, Nuryani S (2017) Characterization and in vitro antifungal assay against *fusarium oxysporum*f. Sp. *passiflorae* of endophytic actinomycetes from purple passion fruit plants of South Sulawesi, Indonesia. Asian J Microbiol Biotech Environ Sci 19(2): 344–353
27. Verma SK, Kingsley KL, Bergen MS, Kowalski KP, White JF (2018) Fungal disease prevention in seedlings of rice (*Oryza sativa*) and other grasses by growth-promoting seed-associated endophytic bacteria from invasive *Phragmites australis*. Microorganisms 6(1):21
28. Cao P, Li C, Wang H, Yu Z, Xu X, Wang X, Xiang W (2020) Community structures and antifungal activity of root-associated endophytic actinobacteria in healthy and diseased cucumber plants and *Streptomyces* sp. HAAG3-15 as a promising biocontrol agent. Microorganisms 8(2):236
29. Ramesha KP, Mohana NC, Nuthan BR, Rakshith D, Satish S (2020) Antimicrobial metabolite profiling of *Nigrosporasphaerica*

from *Adiantum philippense* L. J Genet Eng Biotechnol 18:66

30. Radhakrishnan M, Vijayalakshmi G, Gopikrishnan V, Jerrine J (2016) Bioactive potential of actinobacteria isolated from certain understudied regions in India. J Appl Pharm Sci 6(8):151–155
31. Li ZF, Wang LF, Feng ZL, Zhao LH, Shi YQ, Zhu HQ (2014) Diversity of endophytic fungi from different *Verticillium*-wilt-resistant *Gossypium hirsutum* and evaluation of antifungal activity against *Verticillium dahliae* in vitro. J Microbiol Biotechnol 24(9):1149–1161
32. Mohamad OA, Li L, Ma JB, Hatab S, Xu L, Guo JW, Li WJ (2018) Evaluation of the antimicrobial activity of endophytic bacterial populations from Chinese traditional medicinal plant *licorice* and characterization of the bioactive secondary metabolites produced by *bacillus atrophaeus*against *Verticillium dahliae*. Front Microbiol 9:924
33. Luu T, Phi Q, Nguyen, Van Dinh M, Pham BN, Do QT (2021) Antagonistic activity of endophytic bacteria isolated from weed plant against stem end rot pathogen of *pitaya* in Vietnam. Egypt J Biol Pest Control 31:14
34. Huang LQ, Niu YC, Su L, Deng H, Lyu H (2020) The potential of endophytic fungi isolated from cucurbit plants for biocontrol of soilborne fungal diseases of cucumber. Microbiol Res 231:126369
35. Ali S, Hameed S, Shahid M, Iqbal M, Lazarovits G, Imran A (2020) Functional characterization of potential PGPR exhibiting broad-spectrum antifungal activity. Microbiol Res 232:126389
36. Landum MC, Do Rosário FM, Alho J, Garcia R, Cabrita MJ, Rei F, Varanda CM (2016) Antagonistic activity of fungi of *Olea europaea* L. against *Colletotrichum acutatum*. Microbiol Res 183:100–108
37. Barra-Bucarei L, France Iglesias A, Gerding González M, Silva Aguayo G, Carrasco-Fernández J, Castro JF, Ortiz Campos J (2020) Antifungal activity of *Beauveria bassiana* endophyte against *Botrytis cinerea* in two *Solanaceae* crops. Microorganisms 8(1):65
38. Nguyen MH, Yong JH, Sung HJ, Lee JK (2020) Screening of endophytic fungal isolates against *Raffaeleaquercus-mongolicae* causing oak wilt disease in Korea. Mycobiology 48(6): 484–494

Anoop Singh
Shaili Srivastava
Dheeraj Rathore
Deepak Pant *Editors*

Environmental Microbiology and Biotechnology

Volume 1: Biovalorization of Solid Wastes and Wastewater Treatment

Springer

Editors
Anoop Singh
Department of Scientific
and Industrial Research (DSIR)
Ministry of Science and Technology
Government of India
New Delhi, Delhi, India

Shaili Srivastava
Amity School of Earth
and Environmental Sciences
Amity University Haryana
Gurugram, Haryana, India

Dheeraj Rathore
School of Environment
and Sustainable Development
Central University of Gujarat
Gandhinagar, Gujarat, India

Deepak Pant
Separation and Conversion Technology
Flemish Institute for Technological
Research (VITO)
Mol, Antwerpen, Belgium

ISBN 978-981-15-6020-0 ISBN 978-981-15-6021-7 (eBook)
https://doi.org/10.1007/978-981-15-6021-7

© Springer Nature Singapore Pte Ltd. 2020
This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors, and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Heavy Metal Pollution: An Insight Towards Its Infiltration, Impact and Remediation

6

M. K. Ramkumar, K. Preeti, K. Varuna, Maulin P. Shah, and S. Senthil Kumar

Abstract

With the environment being constantly prone to threats, the sources of pollution have increased drastically over the past few years. Heavy metals are one of those pollutants that are naturally present in the environment and their accumulation has increased due to human interventions. These heavy metals find their way in to the environment through industrialization. These processes had affected the biological community in such a way that heavy metals are part of the living system. Although certain metals fall under the category of essential components of biological mechanisms, most of the heavy metals are toxic to living organisms. These heavy metals cause oxidative stress in living organisms and also interfere in major molecular mechanisms and change the functional properties, thereby affecting the cell organelles. Due to the adverse effects of these heavy metals,

M. K. Ramkumar
Geobiotechnology Laboratory, National College (Autonomous), Tiruchirappalli, Tamil Nadu, India

National Institute for Plant Biotechnology, New Delhi, India

K. Preeti
Department of Energy and Environmentl, TERI SAS, TERI University, New Delhi, India

K. Varuna
PG and Research Department of Biotechnology and Microbiology, National College (Autonomous), Tiruchirappalli, Tamil Nadu, India

M. P. Shah
Industrial Waste Water Research Lab, Division of Applied & Environmental Microbiology Lab Enviro Technology Limited, Ankleshwar, Gujarat, India

S. S. Kumar (✉)
Geobiotechnology Laboratory, National College (Autonomous), Tiruchirappalli, Tamil Nadu, India

PG and Research Department of Botany, National College (Autonomous), Tiruchirappalli, Tamil Nadu, India
e-mail: senthil@nct.ac.in

© Springer Nature Singapore Pte Ltd. 2020

A. Singh et al. (eds.), *Environmental Microbiology and Biotechnology*,
https://doi.org/10.1007/978-981-15-6021-7_6

developed countries have formed several organizations that emphasize on the permissible limits of these heavy metals emission into the environment. Yet, the levels of heavy metals are not contained. Bioremediation is a promising approach to deal with this issue since this method is highly sustainable. Microbial bioremediation is a highly adopted method to tackle the heavy metal polluted area following different methods. This book chapter discusses the different ways by which these heavy metals are leached into the environment, their mode of affecting the biological systems and the different remedial process that could be incorporated to tackle heavy metals pollution.

6.1 Introduction

Physical conditions and external components encompassing living organisms and influencing their survival are collectively termed as environment (Asati et al. 2016). Pollutants are substances that affect the equilibrium of the environment, hindering survival resulting in increased mortality. These pollutants find their way into the environment through all possible routes. There are different types of pollutants and they are not always man made. They can be naturally occurring as well. Nonetheless, they could be harmful depending on their site of occurrence and concentration. Around 75% of the elements in the periodic table are classified as metals, whose properties include 'metallic luster, malleability, sonority, ductility, electrical conductivity and the ability to lose electrons forming basic oxides'. In terms of biology, they can be further divided into metalloids (semi-metals), light metals, heavy metals, essential metals, toxic metals, abundant metals, trace metals and micronutrients (Duffus 2002). Heavy metals include a group of 19 elements with similar physical and chemical properties and are remarkably distinct from the remaining 97 metals (Rajeswari and Sailaja 2014). Though we have been using the term 'heavy metal' for almost thousand years, there exists no definite description that would make us understand the term undoubtedly. Metals with physical properties such as specific gravity greater than 5 g/cm^3, density fivefold higher than water (RoyChowdhury et al. 2018), and chemical properties such as high molecular weight and ability to produce highly reactive chemical entities like free radicles, are called as heavy metals. However, the chemical properties are prioritized during classification.

Although certain metals such as zinc and iron, termed as micronutrients, are essential for biological processes, heavy metals are known to induce toxicity even at low concentrations (RoyChowdhury et al. 2018). Even these essential heavy metals could become toxic beyond permissible levels (Pandey and Madhuri 2014). Heavy metals are natural constituents of the earth's crust. And natural phenomena like weathering and volcanic activities, anthropogenic activities including mining, smelting, industrial and agricultural use have increased the abundance of heavy metals in the environment either by releasing or concentrating them (RoyChowdhury et al. 2018). Heavy metals have infiltrated the environment and modified the living organisms in such a way that life forms are now a combination of

both organic and inorganic substances. Heavy metals, which were found in 'trace' before, have now become a serious threat to the environment due to human interventions. Since the middle of nineteenth century, production of heavy metals increased steeply for around 100 years owing to their regular emission into environment (Järup 2003). Heavy metal seeps into the environment through various channels. Atmospheric emission tops all of them due to easy dissemination which affects almost all of living organisms and is of human health concern.

In order to control heavy metal pollution, numerous committees have been formed to create rules and regulations on the emission of heavy metals. The Aarhus Protocol on Heavy Metals was formed in 1998 to control the emission of heavy metals with the focus on three major heavy metals, viz. cadmium (Cd), lead (Pb) and mercury (Hg). The Protocol set guidelines to restrict emissions from various industrial sources, selected combustion and waste incinerators. Furthermore, it laid down stringent limit values for emissions from stationary sources and suggested best available techniques (BAT) for these sources. At the end of twentieth century, however, it decreased and fell by over 50% from 1990 to 2000 but this progress was confined only to developed countries (Ilyin et al. 2004). Despite the measures, pollution by heavy metals has not been successfully contained. This book chapter is focused on expounding the toxic effects of heavy metals with special emphasis on the molecular mechanism behind their toxicity and the different remediation processes that can be utilized to eliminate the prevailing heavy metals in the environment.

6.2 Heavy Metal Ingression into the Soil Ecosystem

Since soil cannot be confined, control measures for soil contamination, instigated by the excess concentration of heavy metals, have never been strict unlike water and air contamination. However, in recent decades, the developed countries have taken soil contamination into consideration and thus soil contamination by heavy metals has now become a prime focus worldwide (Su 2014). The list of heavy metals has increased in the recent years, apart from already existing ones (Tchounwou et al. 2012; Zojaji 2014). Generation rate of heavy metals via man made cycles is more rapid than natural cycles. The concentrations of the metals in discarded products are relatively higher compared to receiving environment. Furthermore, the chemical forms in which they are present in the soil can be changed leading to depreciation in severity (Wuana and Okieimen 2011). The sources by which these heavy metals find their way into the soil ecosystem are as follows:

6.2.1 Natural Sources

Weathering of Rocks During pedogenesis, heavy metals like Cr, Sn, Hg, Pb, etc. are naturally added to the top soil through weathering and breaking of the parent rock. However, these are considered as trace and are rarely toxic.

Volcanoes Volcanoes are known to release high levels of Zn, Pb, Cu and Mn along with harmful gasses. Winds blowing against volcanoes carry dust rich in heavy metals and add particulate compounds in the surrounding areas apart from eruptions.

Evaporation from Seas Sprays and mists from ocean water carry heavy metals in it. These are released into the atmosphere through bubble bursting and evaporation which in turn results in rainfall enriched in heavy metals. (Nagajyoti et al. 2010).

6.2.2 Agricultural Sources

Fertilizers In order to supply the nutrients which are deficit in the soil, fertilizers are added to ensure robust growth of plants. Commonly these fertilizers are organic compounds along with macronutrients like Cu and Mn. However, certain fertilizers are conjugates of inorganic compounds which contain heavy metals as impurities. With the frequent use of these artificially synthesized compounds, heavy metals such as Cd and Pb get accumulated in the soil, eventually leading to toxicity (Zhang and Zhang 2007; Arao et al. 2010). Phosphoric (P) fertilizers are widely used, since their deficiencies directly reflect on the global productivity (AlKhader 2015). Generally, P fertilizers contain higher concentrations of heavy metals than other fertilizers. These fertilizers are predominantly loaded with cadmium (Cd), lead (Pb) and arsenic metalloid (As) (Galadima and Garba 2012). When these types of fertilizers are used for agricultural practices, Cd easily infiltrates into the soil and could be transported to the crops. The proportion of this event has increased rapidly over years (Boyd 2010). A study revealed that P fertilizers such as diammonium phosphate (DAP), monoammonium phosphate (MAP) and single super phosphate (SSP) encompasses heavy metals such as Cd (0.5–7.9 ppm), Pb (1.8–2.2 ppm) and As (2.8–43.0 ppm) (AlKhader and Abu Rayyan 2014).

Pesticides and Manures Use of pesticides to control the insect attack is yet another widely applied modern day agricultural practice. These pesticides are chemical compounds containing heavy metals like Cu, Hg, Mn, Pb and Zn. For example, lead arsenate and Bordeaux mixture (copper sulphate) have been employed for a long time without check, which has created hot spots for these heavy metals in and around agricultural lands (Wuana and Okieimen 2011). Livestock manures and composts that are applied in agricultural lands obtained from poultry wastes and cattle wastes are reported to contain heavy metals like Cu and Zn, as these metals are an important component in their diet. Prolonged application of these animal wastes as manure in agricultural fields, though considered beneficial, also has side effects like accumulation of heavy metals in the soil (Sumner 2000). A study conducted in the northern region of china revealed that application of animal manures led to the accumulation of Cd, Pb, Zn, As, Cu and Cr in the soil (Zhang et al. 2012a, b). In Austria, usage of poultry and pig manures reflected in elevated levels of Cd in the soil (Sager 2007). Cd content was recorded in extremely high quantity in animal manures in the farmlands of Beijing and Fuxin (Li et al. 2010).

6.2.3 Industrial Sources

Human intervention in nature is the biggest cause of elevated heavy metal levels in soil. During industrial mining and tailing, unearthing of rocks and metal ores results in contamination of surrounding areas with heavy metals present in the ores, which are processed and removed as waste. Due to improper management of this waste, it gets leached into the top soil. There are lot many ways by which industrialization could lead to heavy metal build-up in the soil. Some of the important means by which heavy metals enter the soil are discussed below.

- Atmospheric effluents: Atmospheric heavy metal concentration has increased drastically due to the emission of gases from the industries. These heavy metals get dispersed in the atmosphere, which then deposited on the soil surface through natural sedimentation processes (Zhang et al. 2012a, b). In Sweden, effluents in the form of gas from copper and sulphuric acid factories lead to Pb contamination of the surrounding environment and affected the locality owing to the condensation and precipitation over the time (Lin et al. 1998). A Russian chemical factory dealing with sulphuric acid production was found to emit arsenic along with sulphur and vanadium. Urbanization leading to extensive usage of automobiles had led to the contamination of atmosphere and soil with Pb, Zn, Cd, Cr, Cu, etc. Around 50 μg of Pb per litre of the fuel was exhausted from cars and other heavy vehicles (Su 2014).
- Sewage and solid wastes: The use of sewage water in agricultural field has been known to enhance the soil properties for effective crop yield (Behbahaninia et al. 2009). Wastewater management is an important aspect to be considered in cities. Heavy metals present in wastewater sludge are most likely to be transferred to the soil and subsequently in to the ground water table. Improper maintenance can lead to the deposition of metals and metal containing compounds (Tijani 2009). Though sewage irrigation aids in crop irrigation issues, it depends on the type and processing of sewage. Generally, sewage is categorized as sanitary sewage, chemical wastewater, industrial mining wastewater and urban mining mixed sewage (Su 2014). Heavy metals such as Hg, Cd, Pb and Cr are predominantly present in most of the sewage disposals. Solid wastes that are generated from mining pose a major threat to the environment as they are heavily stocked with heavy metals and have easy access to both soil and aquatic environments. These solid wastes could also be household and electronic wastes which to some extent could be removed by incineration. Even so, huge tons of solid wastes remain untreated (Asgele and Gebremedhin 2015).

6.3 Metabolic Destabilization Due to Heavy Metals in the Living System

Metals are indispensable part of metabolic pathways as they bind to S–H groups of enzymes and are called as 'co-factors'. Nevertheless, research evidences suggest that these metals in quantities more than required would lead to adverse effects in living organisms (Strydom et al. 2006). Metal toxicity leading to impaired metabolism is generally classified into three broad mechanisms as follows:

A. Production of ROS (Reactive Oxygen Species) by auto-oxidation and Fenton's reaction
B. Blocking of essential functional groups in bio-molecules
C. Displacement of essential metal ions from bio-molecules (Schutzendubel and Polle 2002).

Owing to their chemical properties and foreign nature, they escape counter mechanisms such as homeostasis, pass through compartments and bind to specific cellular constituents. This in turn has an effect on cellular organelles like mitochondria, lysosomes, endoplasmic reticulum, nuclei and even cell membranes. Metal ions tend to interact with original metals or displace them from their native binding sites in DNA, nucleic acids and other proteins causing DNA damage and conformational changes resulting in cell cycle modifications, carcinogenesis and cell apoptosis (Tchounwou et al. 2012). Moreover, these heavy metals have huge impact on the microbial community.

Diversity and abundance of soil microbes is an indicator for good soil quality. Their stability could be easily disturbed by infiltration of heavy metals that could cause shifts in density, size, pH, respiration rate and enzyme activity of soil and microbes present in it. Heavy metals indirectly interfere with enzymatic actions, toxicity of which results in inhibition of certain key processes, decreasing the population and activity of microbes. Heavy metals display varied effect on the metabolism owing to the differences in their chemical properties and affinities towards the enzymes. For instance, Cu inhibits β-glucosidase activity, Pb decreases activities of urease, catalase, invertase and acid phosphatase, As affects phosphatase and sulphatase activity. Cd negatively impacts protease, urease, alkaline phosphatase, and arylsulphatase activity. Permissible levels and mechanism of toxicity of significant heavy metals are listed in Table 6.1.

6.3.1 Cadmium

Cadmium affects oxidative metabolism in the following ways:

- Decrease in the levels of glycogen due to higher rates of glycogenolysis resulting from the elevated levels of phosphorylase.

Table 6.1 Details on permissible levels and mechanism of toxicity of heavy metals (Source: Sharma et al. 2014; Asati et al. 2016)

S. No.	Metals	Permissible levels		Toxicity in animals	Toxicity in plants	Toxicity in microorganisms
1	Arsenic	50 μg/day	40 mg/kg	1. Lipoate, an intermediate in Krebs cycle, is depleted by As^{3+} leading to inhibition of oxidative phosphorylation and resulting in ATP depletion 2. As^{5+} hydrolyses stable phosphate ester bond in ATP with arsenate ester bond, depleting ATP reserves 3. Inhibits cellular respiration and uncoupling oxidative phosphorylation leads to cellular energy reduction and eventual cell death 4. Binds to thiol or sulphydryl groups and inactivates over 200 enzymes 5. It modifies gene expression and participates in DNA repair, duplication etc.	1. It is an analogue of P and thus competes with it for uptake. It gets metabolized as organo-phospholipids and arseno-sugars and bio-accumulates in the cells 2. In tomato, it reduces fruit yield and leaf's fresh weight 3. In canola, it stunts growth leads to chlorosis and wilting 4. Arsenic reduces seed germination, decrease in seedling height, leaf area and dry matter production in rice	
2	Cadmium	0.4 μ/kg/day	100 mg/kg	1. Decreases levels of glycogen due to increased activity of phosphorylase which participates in glycogenolysis 2. Increases protease activity leading to excessive proteolysis 3. Enzymes participating in Krebs cycle like succinate dehydrogenase, malate dehydrogenase are decreased and thus impairs	1. Decreases nitrogen fixation and ammonia assimilation in soya beans 2. In wheat, seed germination, reduced root and shoot length 3. Inhibits the activity of Fe(III) reductase thereby reducing photosynthesis 4. Depress activity of nitrate reductase in shoots and so decreases the mobility of the nitrate from roots to shoots	1. Denatures proteins 2. Destroys nucleic acids 3. Hinders cell division and transcription 4. Impacts enzymes like protease, urease, alkaline phosphatase, and arylsulphatase

(continued)

Table 6.1 (continued)

S. No.	Metals	Permissible levels		Toxicity in animals	Toxicity in plants	Toxicity in microorganisms
				mitochondria's oxidative metabolism	5. Negatively impacts the uptake, transport and use of elements like Ca, Mg, P and K resulting in chlorosis, growth inhibition, browning of root tips and finally death	
3	Lead	–	200 mg/kg	1. It demonstrates ability to displace bivalent cations (Ca, Mg, Fe) resulting in changes in cell adhesion, protein folding, release of neurotransmitters by interfering with calcium dependent signalling 2. Lead binds to biomolecules like enzymes having sulphydryl and amide groups, altering their configuration 3. It competes with essential metal ions inhibiting action of enzymes like catalase, and δ-amino levulinic acid dehydratase (ALAD), glutathione reductase (GR), glutathione peroxidase (GPX) and glutathione-S-transferase, which are responsible for GSH synthesis	1. Lead bind to sulphydryl groups of enzymes inhibiting their activity 2. Lead acetate inhibits protease and amylase in rice endosperm, inhibiting seedling growth 3. Cell growth is inhibited due to induced stimulation of IAA oxidation 4. Carboxylating enzymes are inhibited thus reducing photosynthetic activity and growth and biomass such as in oats 5. Inhibits root and shoot elongation in Allium sp. and barley 6. It usually gets accumulated in the roots 7. It also decreases protein content, alters water balance and membrane permeability and thus mineral nutrition 8. It is responsible for Inducing oxidative stress	1. Destroys nucleic acids and proteins 2. Inhibits enzyme action and transcription

4	Mercury	1.3 µg/kg	0.3 mg/kg	1. Binds to sulphydryl group of enzyme, affecting heme synthesis in animals 2. It dissociates salts, thereby precipitating proteins and destroying mucosal membranes 3. Induces ROS activity through increased electron mobilization in mitochondria 4. Oxidative stress negatively impacts Ca homeostasis which is essential for activation of several enzymes such as proteases, endonucleases and phospholipases	1. Binds to water channel proteins, obstructing water flow and thus inducing stomatal closure 2. Induces oxidative stress interfering with mitochondrial activities 3. Destroys bio-membranes lipids and cellular metabolism in plants 4. In rice, it decreases plant height, reduces tiller and panicle formation, and reduction in yield 5. In tomatoes it reduces plant height, flowering fruit weight germination rate 6. Chlorosis is noticed on the entire plant on exposure to mercury	1. Denatures proteins 2. Inhibits enzyme action 3. Disrupts cell membrane
5	Chromium	5 µg/m^3	100 µ/kg	1. Cr(IV) is highly mobile and penetrates cell membranes though SO_4^{2-} and HPO_4^{2-} channels 2. Induces production of ROS which denatures proteins and DNA	1. Depresses activity of amylase affecting transport of sugars to the seed, but increases activity of protease, resulting in overall reduction in germination of Cr treated seeds 2. Induces oxidative stress which degrades photosynthetic pigments (chlorophyll and anthocyanins) present in mainly PSI 3. Inhibits electron transport on the enzymes of Calvin cycle	1. Inhibits growth by prolonging lag phase 2. Inhibits oxygen uptake by the micro organism

- Drop in lactate dehydrogenase activity leading to increased lactate levels indicating reduced mobilization of pyruvate to citric acid cycle. Decreased levels of Krebs cycle enzymes such as succinate dehydrogenase and malate dehydrogenase suggesting impairment of mitochondrial oxidative metabolism.
- Enhanced glucose oxidation owing to elevated activity of glucose-6-phosphate dehydrogenase.
- Decreased protein and amino acid levels with increased ammonia, urea and glutamine levels.
- Increased protease activity suggesting increased proteolysis.
- Elevated levels of arginase and glutamine synthetase resulting in production of urea and glutamine through detoxification of ammonia.

6.3.2 Copper

- Inhibitory effect on 8 different phosphofructokinases (PFKs) with a broad phylogenetic range.
- Studies on long-term exposure to copper and in vivo production of CO_2, suggested that activities of 6-phosphogluconate dehydrogenase and glucose-6-phosphate dehydrogenase could be used as a biomarker for copper toxicity in toad oocytes

6.3.3 Fluoride

Fluoride is known to inhibit a large number of biological processes such as photosynthesis, respiration, protein synthesis and enzyme activities of higher plants, green algae, cyanobacteria and bacteria.

- Fluoroaluminate could bind with ADP, GDP and cations, which causes translocation of ATPases and inhibition of metabolic energy synthesis and release, thereby producing negative effect on physiological processes that require energy.
- It could also cause translocation of ions essential for algal growth and multiplication. The reduction in the number of ATPs at low pH could possibly be attributed to the inhibition of the electron transport chain as it is the major energy producing system in cyanobacteria. The reduction in ATP content also brings about the inhibition of 14C assimilation at low pH. This could lead to the decrease in the availability of carbon skeletons. It is postulated that this is responsible for the reduction in nitrogenase and nitrate reductase activities. This reduction in energy may also lead to an inhibition of other enzymes such as glutamine synthetase and urease (Rai et al. 1996).

6.3.4 Zinc

Despite being an essential element for normal enzymatic functioning, Zn in excess quantities is attributed towards reversible anaemia and damage to pancreas and kidneys.

- The two glycolytic enzymes that might be inhibited by increased Zn concentrations are glyceraldehyde-3-phosphate dehydrogenase (GAPDH) and phosphofructokinase which could result in the build-up of glycolytic metabolites upstream of GAPDH and depleted intermediate products downstream and resulting in lower ATP production.
- Zinc is also known for its inhibition of glycolysis, tricarboxylic acid cycle, electron transport chain and glutamate release through its involvement with α-ketoglutarate dehydrogenase complex (KGDHC), lipoamide dehydrogenase (LADH) subunit of the tricarboxylic acid cycle and photosystems (Cytochrome C1) (Dineley et al. 2003).

6.3.5 Lead

Lead is a highly toxic metal that is abundantly found in various products of day-to-day life. The ill-effects of Pb at higher quantities are listed below.

- The ability of lead metal ions to replace other bivalent cations like Ca^{2+}, Mg^{2+}, Fe^{2+} and monovalent cations like Na^{+} ultimately disturbs the biological metabolism of the cell. The ionic mechanism of lead toxicity causes significant changes in various biological processes such as cell adhesion, intra- and inter-cellular signalling, protein folding, maturation, apoptosis, ionic transportation, enzyme regulation, and release of neurotransmitters. Pb could replace calcium even in picomolar concentration affecting protein kinase C, which regulates neural excitation and memory storage (Flora et al. 2012).
- Pb is involved in the inhibition of glycolysis, heme and globin synthesis thereby influencing the metabolism of erythrocytes.
- Formation of covalent attachments is one of the properties of Pb. These attachments are formed between Pb moiety and the sulphydryl groups present in antioxidant enzymes, which are the most susceptible targets for Pb and which eventually get inactivated. Pb also inactivates glutathione by binding to sulphydryl groups present in it. This results in synthesis of GSH from cysteine via the γ-glutamyl cycle, which is usually not effective in replenishing the supply of GSH (Jan et al. 2015). Similarly, Pb inactivates enzymes like δ-aminolevulinic acid dehydratase (ALAD), glutathione reductase (GR), glutathione peroxidase (GPX) and glutathione-S-transferase, which further depresses the glutathione levels (Ahamed and Siddiqui 2007). A few other notable antioxidant enzymes that are rendered inactive by Pb includes superoxide dismutase (SOD) and catalase (CAT). Decrease in SOD concentration reduces the disposal of

superoxide radical, whereas reduction in CAT impairs scavenging of superoxide radical. Apart from targeting sulphydryl groups, Pb can also replace Zn ions which serve as the vital co-factor for these antioxidant enzymes and thereby inactivating them (Flora et al. 2006).

- Lipid peroxidation is another biomarker of oxidative stress and is one of the most investigated consequences of ROS on lipid membranes. The generated free radicals capture electrons from the lipids present inside the cell membranes and damage the cell. Apart from lipid peroxidation, Pb also causes haemoglobin oxidation, which directly causes RBC hemolysis. This occurs due to inhibition of ALAD, which results in an increased concentration of substrate, ALA, in both blood and urine. These elevated ALA levels generate hydrogen peroxide, superoxide radical and also interact with oxyhaemoglobin, resulting in the generation of hydroxyl radicals. Progression of all the above mentioned mechanisms makes the cell extremely vulnerable to oxidative stress and may lead to cell death.

6.3.6 Arsenic

- As generates severe effects by binding with the sulphydryl groups of vital enzymes and depleting lipoate by trivalent arsenite. Lipoate is involved in the synthesis of key intermediates in the Krebs cycle. Hence, the depletion of lipoate results in inhibition of the Krebs cycle and oxidative phosphorylation leading to ATP depletion.
- Pentavalent arsenate, on the other hand, can replace the stable phosphate ester bond in ATP with arsenate ester bond, thereby rapidly hydrolyzing ATP (arsenolysis) and uncoupling oxidative phosphorylation resulting in the depletion of ATP stores. The combined action of inhibiting cellular respiration and uncoupling oxidative phosphorylation results in cellular energy depletion, causing cell death in tissues with high energy requirement.

6.3.7 Mercury

- Mercury binds to sulphydryl groups (–SH groups) of proteins and inhibits heme biosynthesis. Heme is the essential structural component of haemoglobin, myoglobin, and cytochromes.
- Hg is involved in the destruction of mucosal membranes, necrosis of proximal tubular epithelium and precipitation of proteins through dissociation of salts.

6.4 Microbial Remediation of Heavy Metal Poisoning

Remediation is employed to control and minimize heavy metal toxicity in contaminated water, soil and to sustain the living organisms dependent or residing in it. It is essential to ensure their healthy growth and to maintain biodiversity of that region. Figure 6.1 represents the broad classification of remediation based on the mode of operation.

6.4.1 Physical Methods

Techniques used under physical remediation are as follows:

Soil Replacement Contaminated soil is excavated, so that the site could be filled with uncontaminated soil. This is employed only for extreme cases of contamination as it is expensive and requires working in large volumes.

Soil Isolation Using sub-surface barriers, contaminated soil is physically separated from uncontaminated area. It restricts further contamination and used for highly contaminated soils.

Vitrification Bioavailability of heavy metals could be reduced by forming vitreous material from either decomposition or volatilization of organic matter, when heating the soil at temperatures around 14,000C–20,000C. It is easily applicable to lot of contaminants though it is expensive due to high energy requirement.

Electrokinetic Remediation This is an in-situ process where the soil is heated using electrodes, which pass direct current (DC) through damp soil for heavy metals' removal. It is easy, cost effective and maintains the nature of soil (Khalid et al. 2017; RoyChowdhury et al. 2018).

As discussed above, most of the physical remediation methods are generally tedious and expensive.

6.4.2 Chemical methods

It involves the usage of various chemical compounds to remove heavy metals from the area of contamination. Some of the methods are as follows:

Immobilization Heavy metals such as clay, cement, organic compost and zeolites are used to immobilize the soluble forms of metals that are bio-available, by forming stable complexes.

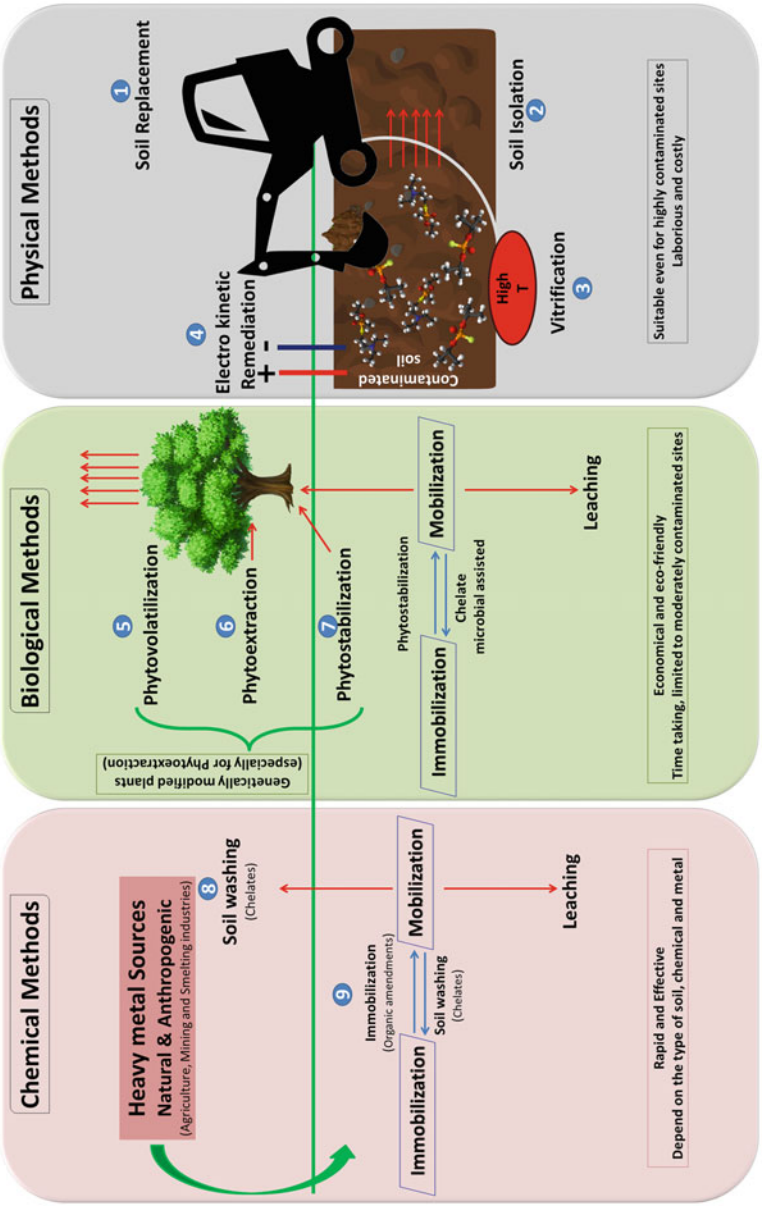


Fig. 6.1 Methods of heavy metal remediation (source: Khalid et al. 2017)

Extraction It is also called soil washing because chemical agents (organic and inorganic) which can chelate or elute the heavy metals are added to bring the metals into aqueous phase by forming stable complexes, and thus extracting them from the system (Khalid et al. 2017; RoyChowdhury et al. 2018).

6.4.3 Biological Remediation

Biological remediation is the application of living organisms for the treatment of polluted areas (RoyChowdhury et al. 2018). It could be microorganisms or plants. Through bioremediation, only oxidation state of heavy metals is changed, therefore it is not degraded. However, due to this modification, alterations in their vaporization and solubilization properties occur, which make the process of leaching out (more water soluble) or precipitation (less water soluble) of heavy metals easier. Though it is a natural method, it takes long time and happens gradually over the span of years.

Phytoremediation This method is employed for wide-spread contamination which is present till the root zone of the plant. The plants utilized for this method have hyper-accumulating properties towards certain heavy metals and thus remove it from the soil.

Phytoextraction Hyper accumulator plants (10–500 times more than ordinary plants) (Chibuike and Obiora 2014) are used which have high tolerance to toxic effects of heavy metals, rapid growth rate, high biomass and extensive roots. They absorb, translocate and concentrate heavy metals in their tissues. These plants are then harvested and incinerated and thus purifying the soil from heavy metals. Pteris vittata for As, Brassica juncea for Pb and Arabidopsis halleri for Cd are a few examples for hyper-accumulators.

Phytostabilization Specific plants are known to immobilize ions by absorption and accumulation. These ions are absorbed into the roots or precipitated in rhizosphere. Through this, bioavailability of metals to living organisms is reduced via sequestration in plant roots. Solanum nigrum is shown to phytostabilize Zn.

Phytovolatilization Plants take up heavy metals from the soil and release it into the atmosphere in the form of vapour. This method is mostly used for remediation of soil from Hg contamination. Toxic Hg ions are converted into elemental Hg and transpired into the atmosphere. *Nicotiana tabacum*, *Arabidopsis thaliana*, *Liriodendron tulipifera* are used for Hg and *Brassica juncea* and *Brassica napus* for Se remediation through phytovolatilization (Chibuike and Obiora 2014; Dixit et al. 2015; Khalid et al. 2017).

6.4.3.1 Microbial Remediation

Microbial remediation involves the usage of microbes to reduce heavy metals through absorption, precipitation, oxidation or reduction of these metals. Algae,

fungi and bacteria could perform microbial remediation. Microbes are known to display biosorption of heavy metals. Biosorption is defined as sequestering metals, intra or extracellularly, and thus removing it from the surrounding areas. The mechanism is of two types, viz. Active and Passive.

Active Mechanism (Direct Changes in Metals)

Precipitation Soluble metal ions are converted into insoluble products thereby reducing the transportation and bioavailability of these heavy metals. Anaerobic bacteria like Desulfovibrio and Desulfotomaculum produce hydrogen sulphide which reacts with these metal ions (cadmium, copper, lead and mercury) to produce insoluble metal sulphides.

Intracellular Accumulation This process takes place in two steps: firstly, the heavy metals bind to the surface in a passive manner and then enter the cell slowly with the expenditure of energy, that being the second step. Complexation of these ions occurs in the cell's cytoplasm through various compounds. *Rhizobium leguminosarum* and *Pseudomonas putida* have demonstrated resistance to Cd and its ability of intracellular sequestration.

Reduction Toxic oxidation states of heavy metals are converted into non-toxic forms thus eliminating its harmful effects. For example, Bacillus subtilis, Pseudomonas putida and Enterobacter cloacae have been found to reduce Cr(VI) to Cr(III). Similarly, Desulfovibrio vulgaris precipitates soluble U6+ to U4+. Reductase enzymes produced by these bacteria are responsible for this mechanism.

Passive Mechanism (Alteration of Heavy Metal Surroundings)

Extracellular Complexation This occurs from interactions between metal ions and chelating agents released by the microbes present in the soil. These chelating agents could be extracellular polymers like polysaccharides, proteins and nucleic acids or could be low molecular ligands called siderophores (Fe complexing molecules). These agents form complexes with the heavy metals, and negatively impact its bioavailability. *Bacillus thuringiensis* and *Bacillus subtilis* are known to secrete siderophores that increase extraction of Cd and Zn by increasing its mobility and thus their ability to be extracted.

Surface Adsorption It is the accumulation of heavy metals on the complexes and components present on the periplasm of the cell. It occurs in three ways, namely ion exchange with peptidoglycan and teichoic acid present on the cell wall, precipitation through nucleation reaction and complexation with nitrogen and oxygen ligands.

Dead Microbes Dead microbes also tend to accumulate heavy metals on their surface (Gavrilescu 2004; Igiri et al. 2018).

6.4.3.2 Microbes Involved in Bioremediation

Bacteria for Bioremediation Bacteria are the most versatile and abundant microorganisms for the remediation of heavy metal based on certain characters such as number of surface binding sites, binding strength for different ions and its binding mechanisms. They are highly preferred because of their small size, ubiquitous nature and the capacity to grow in a wide range of controlled and environmental conditions due to which they have developed many mechanisms to detoxify and develop resistance against heavy metals.

Algae for Bioremediation Algae are cheap and efficient microbes owing to their autotrophic nature and minimal requirement for nutrients. Algae can absorb from 15.3% to 84.6% of heavy metals due to their high biosorptive capacity. Out of all the algae, brown algae sequester most of the heavy metals. This is due to the presence of several chemical moieties on its surface such as hydroxyl, carboxyl, phosphate and amide groups which act as metal binding sites.

Fungi for Bioremediation Fungi are useful in both dead and alive condition due to their remarkable capacity for heavy metal uptake. They are easy to grow in fermentors and are easily available from industries. Fungus produces large quantities of extracellular enzymes and chemicals and also provides larger surface, thus increasing the availability of cell wall materials. Filamentous fungi are advantageous over yeast because the former is easily filtered and is less sensitive to variations in nutrients, aeration, pH and temperature (Abbas et al. 2014; Mustapha and Halimoon 2015).

6.4.3.3 Types of Microbial Bioremediation

In a broad spectrum, microbial bioremediation is categorized into two types, viz. in situ and ex situ bioremediation depending on the mode of the utilization.

In Situ Bioremediation His method involves application of bioremediation in the sub-surface which provides thorough end result. It is less expensive and more effective. It is further divided into two categories.

1. *Intrinsic in situ bioremediation*: It utilizes the naturally occurring microbes and does not incorporate any engineering techniques and employs only the capabilities of already present microbes. These microbes are fed nutrients and it is regularly aerated to increase their metabolic activity.
2. *Engineered in situ bioremediation*: Certain microbes of known beneficial properties are artificially introduced in to the site. Detoxification rate is increased by controlling physiochemical conditions for maximum growth of microorganism.

Ex Situ Bioremediation In this method, soil is excavated and lined above the ground in a treatment area and is subjected to aeration ad several processes so as to

enhance microbial degradation. Ex situ bioremediation has several sub-categories such as

1. *Slurry-phase treatment*: Also known as bioreactors; it changes the soil into slurry by addition of water and placing in a bioreactor after removal of stones, rubble and debris. Followed by this, the soil is removed and contaminated water is sent for further treatment. Meanwhile the soil is dried up using pressure filter, vacuum filter or centrifuges.
2. *Solid-phase treatment*: This method directly uses the contaminated soil without processing it. With the help of networked pipe system, the entire pile of soil is aerated for encouraging the action of microbes already present in the excavated soil. This method involves more time and space as compared to slurry-phase treatment.

6.4.3.4 Implications of Bioremediation

Advantages

1. Bioremediation is a natural process and is widely accepted.
2. Less energy is required as compared to other processes.
3. It is less expensive than other technologies.
4. It is a complete process where the toxic substances are completely transformed into harmless products.
5. Instead of transferring contaminants from one place to another, the pollution is contained and degraded at the site itself.

Disadvantages

1. Biological processes are highly specific and require optimum conditions for its success.
2. Requires longer duration than other treatment methods.
3. It is a dynamic process and it is difficult to predict the outcome.
4. Only biodegradable compounds can be degraded through this method (Kulshreshtha et al. 2014).

6.4.3.5 Genetic Engineering in Bioremediation

Genetically Engineered Microorganisms (GEMs) include those organisms that have undergone genetic modifications, either to alter the expression of certain characters or to incorporate certain traits into an organism that was originally lacking it. Through genetic engineering, biosensors have also been developed which could detect and measure the degree of contamination in a polluted site rapidly and accurately, for heavy metals such as Hg, As, Cd, Ni, Cu, etc. GEMs are engineered with characteristics such as the ability to tolerate high levels of heavy metal stress and the ability to produce metal chelating (Bae et al. 2000). Some of the commonly used GEMs are Escherichia coli (ELP153AR) to target As, Saccharomyces cerevisiae (CP HP3) to target Cd^{2+}, Zn^{2+} and also for their remediation. Chlamydomonas reinhardtii was engineered to increase resistance to Cd toxicity and accumulation (Dixit et al. 2015; Igiri et al. 2018).

6.5 Future Endeavours Towards Controlling Heavy Metal Pollution

Human intrusion has led to the contamination of environment with high levels of heavy metals. International protocols such as Convention on Long-Range Transboundary Air Pollutants (LRTAP), Rotterdam Convention, The Basel Convention, and International Convention on the Control of Harmful Anti-Fouling Systems on Ships, etc., aim to reduce and stabilize the existing levels of heavy metals. Apart from these protocols and norms, alternatives to heavy metals can also be used so as to control the emission of heavy metals. Some of the alternatives corresponding to the heavy metals are listed below.

Lead Lithium-ion polymer batteries can be used instead of lead acid batteries. Steel, soft iron, wolfram, bismuth and tin maybe used as alternatives to lead in ammunition. Iron, copper and plastic pipes could also be used in industries instead of lead pipes. In paint industries, instead of lead based siccatives, calcium based siccative can be used.

Mercury Amalgams and cast fillings in dentistry can use ceramics, gold or silver as alternative to mercury. Electrical thermometers can be used instead of the traditional glass thermometers. Pesticides using mercury could be avoided. It is better not to use pesticides at all.

Cadmium Lithium-ion polymer batteries can be used instead of cadmium–zinc batteries. Voltage stabilizers made of PVC containing calcium instead of cadmium can be used. Photovoltaic cells made of traditional crystalline cells could be an alternative to cadmium film based cells.

Chromium Chromium based leather tanning could be replaced with synthetic organic compounds based tanning. Cu, Cr, As based wood preservatives could be replaced with Cu, B—organic compounds based preservatives.

6.6 Conclusion

Heavy metal contaminated soils pose a serious threat to the global food security considering the fact that heavy metals are considered as one of the major abiotic stress. And also, the agricultural ecosystem is being deeply affected leading to serious health effects in humans. In order to contain the toxicity levels in the soil and to recover fertility of the heavy metal affected area, developed countries have taken necessary steps to reduce and to regulate their emission. Despite these precautions, the reduction in the heavy metal levels is nominal. Moreover, it is rarely being considered as a threat among the developing countries. To achieve a global success in reducing metal toxicity, awareness has to be created among people and government has to frame strict rules and regulations for factories emitting such toxic

compounds. Traditional agricultural practices have to be followed in order to avoid the usage of chemical fertilizers and pesticides which is a two-way benefit. With the tremendous development in technology, instruments for the accurate measurement levels of heavy metals could be developed. As far as the containment of the prevailing contamination is concerned, genetically engineered microbes with multiple metal targets and new molecular biological tools could be developed and utilized. Phytoremediation is yet another option as it not only detoxifies the soil but also purifies the atmosphere. Therefore, containment and maintenance of heavy metal concentration in the environment could be brought by the combined efforts of the research community, industrial sector and government. Success comes with commitment after all!

References

Abbas SH, Ismail IM, Mostafa TM, Sulaymon AH (2014) Biosorption of heavy metals: a review. J Chem Sci Technol 3(4):74–102

Ahamed M, Siddiqui MKJ (2007) Low level lead exposure and oxidative stress: current opinions. Clin Chim Acta 383(1-2):57–64

AlKhader AMF (2015) The impact of phosphorus fertilizers on heavy metals content of soils and vegetables grown on selected farms in Jordan. Agrotechnology 4(137):2

AlKhader AM, Abu Rayyan AM (2014) Effects of phosphorus fertilizer type and rate on plant growth and heavy metal content in lettuce (Lactuca Sativa L.) grown on calcareous soil. Jordan J Agric Sci 173(3834):1–15

Arao T, Ishikawa S, Murakami M, Abe K, Maejima Y, Makino T (2010) Heavy metal contamination of agricultural soil and countermeasures in Japan. Paddy Water Environ 8(3):247–257

Asati A, Pichhode M, Nikhil K (2016) Effect of heavy metals on plants: an overview. Int J Appli Innov Eng Manage 5(3):56–66

Asgele T, Gebremedhin K (2015) Heavy metals analysis in solid municipal wastes. Int J Technol Enhanc Merg Eng Res 3(2):7–10

Bae W, Chen W, Mulchandani A, Mehra RK (2000) Enhanced bioaccumulation of heavy metals by bacterial cells displaying synthetic phytochelatins. Biotechnol Bioeng 70(5):518–524

Behbahaninia A, Mirbagheri SA, Khorasani N, Nouri J, Javid AH (2009) Heavy metal contamination of municipal effluent in soil and plants. J Food Agric Environ 7(3-4):8

Boyd RS (2010) Heavy metal pollutants and chemical ecology: exploring new frontiers. J Chem Ecol 36(1):46–58

Chibuike GU, Obiora SC (2014) Heavy metal polluted soils: effect on plants and bioremediation methods. Appl Environ Soil Sci 2014:752708

Dineley KE, Votyakova TV, Reynolds IJ (2003) Zinc inhibition of cellular energy production: implications for mitochondria and neurodegeneration. J Neurochem 85(3):563–570

Dixit R, Malaviya D, Pandiyan K, Singh U, Sahu A, Shukla R et al (2015) Bioremediation of heavy metals from soil and aquatic environment: an overview of principles and criteria of fundamental processes. Sustainability 7(2):2189–2212

Duffus JH (2002) "Heavy metals" a meaningless term? Pure Appl Chem 74(5):793–807

Flora SJ, Flora G, Saxena G (2006) Environmental occurrence, health effects and management of lead poisoning. In: Lead. Elsevier, Cambridge, pp 158–228

Flora G, Gupta D, Tiwari A (2012) Toxicity of lead: a review with recent updates. Interdiscip Toxicol 5(2):47–58

Galadima A, Garba ZN (2012) Heavy metals pollution in Nigeria: causes and consequences. Elixir Pollut 45(2012):7917–7922

Gavrilescu M (2004) Removal of heavy metals from the environment by biosorption. Eng Life Sci 4 (3):219–232
Igiri BE, Okoduwa SI, Idoko GO, Akabuogu EP, Adeyi AO, Ejiogu IK (2018) Toxicity and bioremediation of heavy metals contaminated ecosystem from tannery wastewater: a review. J Toxicol 2018:12
Ilyin I, Berg T, Dutchak S, Pacyna J (2004) Heavy metals. EMEP assessment part I European perspective. Norwegian Meteorological Institute, Oslo, pp 107–128
Jan AT, Azam M, Siddiqui K, Ali A, Choi I, Haq QMR (2015) Heavy metals and human health: mechanistic insight into toxicity and counter defense systemn of antioxidants. Int J Mol Sci 16:29592–29630
Järup L (2003) Hazards of heavy metal contamination. Br Med Bull 68(1):167–182
Khalid S, Shahid M, Niazi NK, Murtaza B, Bibi I, Dumat C (2017) A comparison of technologies for remediation of heavy metal contaminated soils. J Geochem Explor 182:247–268
Kulshreshtha A, Agrawal R, Barar M, Saxena S (2014) A review on bioremediation of heavy metals in contaminated water. IOSR J Environ Sci Toxicol Food Technol 8(7):44–50
Li YX, Xiong X, Chun-ye L, Feng-song Z, Wei L, Wei H (2010) Cadmium in animal production and its potential hazard on Beijing and Fuxin farmlands. J Hazard Mater 177(1-3):475–480
Lin Z, Harsbo K, Ahlgren M, Qvarfort U (1998) The source and fate of Pb in contaminated soils at the urban area of Falun in central Sweden. Sci Total Environ 209(1):47–58
Mustapha MU, Halimoon N (2015) Microorganisms and biosorption of heavy metals in the environment: a review paper. J Microb Biochem Technol 7:253–256
Nagajyoti PC, Lee KD, Sreekanth TVM (2010) Heavy metals, occurrence and toxicity for plants: a review. Environ Chem Lett 8(3):199–216
Pandey G, Madhuri S (2014) Heavy metals causing toxicity in animals and fishes. Res J Anim Vet Fish Sci 2(2):17–23
Rai LC, Husaini Y, Mallick N (1996) Physiological and biochemical responses of Nostoc linckia to combined effects of aluminium, fluoride and acidification. Environ Exp Bot 36(1):1–12
Rajeswari TR, Sailaja N (2014) Impact of heavy metals on environmental pollution. J Chem Pharm Sci 3:175–181
RoyChowdhury A, Datta R, Sarkar D (2018) Heavy metal pollution and remediation. Green Chem 2018:359–373
Sager M (2007) Trace and nutrient elements in manure, dung and compost samples in Austria. Soil Biol Biochem 39(6):1383–1390
Schutzendubel A, Polle A (2002) Plant responses to abiotic stresses: heavy metal-induced oxidative stress and protection by mycorrhization. J Exp Bot 53(372):1351–1365
Sharma B, Singh S, Siddiqi NJ (2014) Biomedical implications of heavy metals induced imbalances in redox systems. Biomed Res Int 2014:640754. https://doi.org/10.1155/2014/640754
Strydom C, Robinson C, Pretorius E, Whitcutt JM, Marx J, Bornman MS (2006) The effect of selected metals on the central metabolic pathways in biology: a review. Water 32(4):543–554
Su C (2014) A review on heavy metal contamination in the soil worldwide: situation, impact and remediation techniques. Environ Skept Crit 3(2):24
Sumner ME (2000) Beneficial use of effluents, wastes, and biosolids. Commun Soil Sci Plant Anal 31(11-14):1701–1715
Tchounwou PB, Yedjou CG, Patlolla AK, Sutton DJ (2012) Heavy metal toxicity and the environment. In: Luch A (ed) Molecular, clinical and environmental toxicology, Experientia supplementum, vol 101. Springer, Basel
Tijani MN (2009) Contamination of shallow groundwater system and soil–plant transfer of trace metals under amended irrigated fields. Agric Water Manag 96(3):437–444
Wuana RA, Okieimen FE (2011) Heavy metals in contaminated soils: a review of sources, chemistry, risks and best available strategies for remediation. Isrn Ecol 2011:402647
Zhang W, Zhang X (2007) A forecast analysis on fertilizers consumption worldwide. Environ Monit Assess 133(1-3):427–434

Zhang F, Li Y, Yang M, Li W (2012a) Content of heavy metals in animal feeds and manures from farms of different scales in northeast China. Int J Environ Res Public Health 9(8):2658–2668
Zhang X, Yang L, Li Y, Li H, Wang W, Ye B (2012b) Impacts of lead/zinc mining and smelting on the environment and human health in China. Environ Monit Assess 184(4):2261–2273
Zojaji F (2014) Bioaccumulation of chromium by Zea mays in wastewater-irrigated soil: an experimental study. Proc Int Acad Ecol Environ Sci 4(2):62

PRINCIPLES OF MANAGEMENT



A. Narasima Venkatesh
Dr. Lekshmi. R. S
Dr. M. A. Parveen Banu
Dr. V. Rathnamani

Principles of Management

A. Narasima Venkatesh
Dr. Lekshmi. R. S
Dr. M. A. Parveen Banu
Dr. V. Rathnamani

GOOD WRITERS PUBLISHING
(Since 2011)
www.goodwriters.in

GOOD WRITERS PUBLISHING

RZ 94, Sector - 6, Dwarka, New Delhi - 110075
Shubham Vihar, Mangla, Bilaspur, Chhattisgarh - 495001

Website: *www.goodwriters.in*

© Copyright, 2023, Author

All rights reserved. No part of this book may be reproduced, stored in a retrieval system, or transmitted, in any form by any means, electronic, mechanical, magnetic, optical, chemical, manual, photocopying, recording or otherwise, without the prior written consent of its writer.

ISBN: 978-93-5756-881-4

Price: Rs.500.00

The opinions/ contents expressed in this book are solely of the author and do not represent the opinions/ standings/ thoughts of Publisher.

Printed in India

SOCIAL, ECONOMIC, EDUCATIONAL AND ENVIRONMENTAL IMPACT OF COVID -19 ISSUES AND CHALLENGES



Editors

Dr.C.PARAMASIVAN

Dr.PRANAM DHAR

Dr.K.KRISHNAKUMAR

Published by :

INDIAN ACADEMIC RESEARCHERS ASSOCIATION

TIRUCHIRAPPALLI

SOCIAL, ECONOMIC, EDUCATIONAL AND ENVIRONMENTAL IMPACT OF COVID-19 ISSUES AND CHALLENGES

Editors :
Dr.C.PARAMASIVAN
Dr.PRANAM DHAR
Dr.K.KRISHNAKUMAR

Published by :
INDIAN ACADEMIC RESEARCHERS ASSOCIATION
TIRUCHIRAPPALLI

Book Name : **SOCIAL, ECONOMIC, EDUCATIONAL AND ENVIRONMENTAL IMPACT OF COVID -19 ISSUES AND CHALLENGES**

First Edition : **Nov. 2020**

Editors : **Dr.C.Paramasivan**
Dr.Pranam Dhar
Dr.K.Krishnakumar

Copyright : **Authors**

Pages : **XVI+324**

Paper : **JK Copier 75GSM**

Size : **Copier B5 Size (182mm x 257mm)**

ISBN : **978-81-948552-0-0**

Price : **₹.800**

Printed By : **Tharsan Printers**
Tiruchirappalli - 620 021.
Tamil Nadu, INDIA.
tharsanprinters@gmail.com

Published By : **INDIAN ACADEMIC RESEARCHERS ASSOCIATION**
Tiruchirappalli - 620 021,
Tamil Nadu, INDIA.
www.iaraindia.com

AN IMPACT OF COVID-19 PANDEMIC CRISIS ON INDIAN ECONOMY

K.Sivasakthi
Assistant Professor,
MBA Department,
J.J. College of Engg., &Technology, Trichy-9

Dr. M.Chandra
Assistant Professor,
Department of Commerce,
National College(Autonomous), Trichy-1

Abstract

*The Corona virus was first identified in December 2019 in China which spread at an eagle's pace in the world, and brought the global economy to its knees. What is the proxy to COVID-19 in terms of economic crises and how this deadly virus stopped the economic as well as social activities? The influence of the virus could be seen in two ways: at one side it affect the close proximity by practicing social distancing which further led the shutdown of institutions, offices, shopping malls etc. whereas, on other hand economic actors such as consumers, investors etc unable to predict that how long the effect of virus spread will last. This paper attempts to explore how COVID-19 effects global businesses and what are the short-term measures taken by governments to minimize its impact upon the health of their nations and on their economies. This study attempted to focus the entire measures and policies (fiscal policies, monetary policies, and health policies) adopted worldwide to tackle the situation emerged due to corona outbreak. In addition the impact of social distancing on economic activities and stock market indices was also examined. The outcomes indicated a negative relationship between lockdown, travel restrictions, monetary policy, economic activities, and **stock** market; whereas, positive relationship was found between fiscal policy, internal movements and economic activities; however, no significant relationship was found in rise of number of confirmed cases and economic activates.*

Key words: *COVID-19, market volatility, dislocation, financial markets*

Introduction

Foreign trade plays a very important role in the economy of India. India import and export large number of products and services with many countries all over the world. As it has been seen that COVID-19 pandemic has affected the global economy severely and as such global trade. So, an attempt has been made to study the impact of COVID-19 on foreign trade of India. The study is made to know the trend of India's foreign trade during and before the pandemic and also to make a comparison on the growth of foreign trade with corresponding period of the preceding year. The nature of the study is descriptive and analytical. The data have been collected from secondary sources on foreign trade from government websites and analysed with the help of graphs and tables prepared in Microsoft Excel. The study revealed that the pandemic has negative impact on India's foreign trade. Massive contraction has been seen in the export and import specially in the month of April. But during this crisis India earns surplus trade balance for the first time after liberalisation. This surplus is observed due to decline in import rather than escalation in export.

The recent outbreak of coronavirus named COVID-19 has created a scenario filled with uncertainties for the entire world. Intense Market volatility and dislocation across industries have been caused as a result of this pandemic situation which may not be contained as

 ISBN : 978-81-948552-0-0



Dr.C.PARAMASIVAN is an Assistant Professor in the PG and Research Department of Commerce, Periyar E.V.R College (Autonomous), Tiruchirappalli, Tamil Nadu. He has completed M.Com (Business Finance) from Pondicherry Central University, M.Phil from the Gandhigram Rural University, Dindigul and successfully completed Ph.D from Periyar University, Salem. He also obtained M.A Economics, M.B.A Finance, M.Sc Psychology and M.L.I.Sc. Apart from that, he also secured certain diplomas like PGDCA, DPMIR, and CPEd from the reputed institutions. He passed SLET in Commerce and NET in Management. He has teaching experience for over 20 years and produced 60 M.Phil and 15 Ph.D. He is specialized in Business Finance, Entrepreneurship Development, Research Methodology, and Women Empowerment.

He published books entitled on Financial Management, Financing of Small Industries, Human Rights, Information Technology in Financial Sector, Research Methodology and Women Empowerment, Bank Finance to SSI, Inclusive Banking through Technology, Financial inclusion for Inclusive Growth, Dalit Women Empowerment through Micro Finance ,Micro Enterprise Prospects and Problems social entrepreneurship , Financial Inclusion for Inclusive Growth, fostering scientific temper on Business Research , Consumer Exploitation in Organized Retailing , Inclusive Banking through PMJDY, Dalit Entrepreneurship in Tamil Nadu, Institutional Assistance to Dalit entrepreneurs , Corporate Social Responsibility, Economic Empowerment of Tribal Women through SHG, Sathanaikal Sathiyame (Tamil) and three anthologies of poems in Tamil. He published more than 150 research articles in National and International journal and presented about 50 papers in National and International seminars. He has completed sponsored research projects funded by NTS India, MHRD, UGC, and ICSSR. He has organized many seminars and workshops in association with UGC, ICSSR, RGNIYD, NHRC and ICT ACT and acted as resource person and Chairperson in various national and international level seminars.



Dr. PRANAM DHAR is acting as the Associate Professor in the Department of Commerce & Management, West Bengal State University, Barasat, Kolkata. He is also the Chairman, in the various under-graduate and post-graduate boards of studies of several universities in India & Programme Co-ordinator, NSS, West Bengal State University. He completed his master degree in Commerce from the University of Calcutta with 1st Class and stood second in 1995. He has passed both NET and SLET in 1997. He completed his Ph.D. Degree from the Department of Business Management, University of Calcutta in February, 2008. Dr. Dhar has a full-time teaching experience of 22 years. He has authored Twenty (42) books and also One Hundred and Three(228) research articles published in different regional, national & international journals. He has supervised 20 M.Phil Dissertations and 09 Ph.D. Dissertations. He has also completed 3 (Three) UGC-Sponsored Minor Research Projects till date and also completed 1(one) Major Research Project Sponsored by the Indian Council of Social Science Research (ICSSR). He has also been awarded with two D.Litt. (H.C.) degrees for his contribution to the area of management, finance and banking. He is the reviewer of 18 International and 26 National Journals including Inderscience, Emarald and other scopus-indexed journals. He has received many Awards'. He is nominated as the All-India President and State President, Indian Academic Researchers' Association, West Bengal Wing, EC Member of Indian Accounting Association, South Bengal Branch and members in other eminent academic, professional and social bodies.



Dr.K.KRISHNAKUMAR, Associate Professor, Department of Commerce, Periyar University, Salem, Tamil Nadu, India, has qualified with M.Com, M.Phil, MBA., Ph.D. He is having 20 years of teaching, 15 years of research and 6 years of industrial experiences. He has published more than 120 articles in UGC listed, peer reviewed, and Scopus indexed journals and authored 2 text books. He is running a Major Research Project funded by ICSSR. He has participated and presented papers in more than 150 National and International Conferences and Seminars. So far he has guided 9 Ph.D scholars and currently 6 scholars are pursuing their Ph.D. He actively participates as a resource person in various seminars and conferences and delivered more than 75 special addresses and invited talks in various institutions. He is a life member of Indian Accounting Association and Indian Academic Researchers Association. So far he has registered nine copy rights for his research models in copy right office, India. He is the associate editor and editorial board member of various National and International journals. He received Bharat Jothi award, Best citizens of India Award, Best Research Advisor Award, Best Social Scientist Award, Bharat Excellence Award and Best Educationalist in India Award from various reputed institutions. He was two foreign visits to his credit.

Printed at :

Tharsan Printers, Tiruchirappalli

ISBN 978-81-948552-0-0

9 788194 855200

ISBN: 978-93-95341-79-0

BIG DATA FOR ANALYTICS



Authors

Dr.P.S.S.Akilashri | Ms.S.Thulasi Bharathi
Mrs.G.Nithya | Mrs.A.Ahadha Parveen
Mrs.B.Divya Prabha

BIG DATA FOR ANALYTICS

Dr.P.S.S.AKILASHRI
Associate Professor,
Department of Computer Science,
National College (Autonomous),
Trichy, Tamil Nadu, India.

Ms.S.Thulasi Bharathi
Assistant Professor,
Department of Computer Science,
St. Joseph's College (Autonomous),
Tiruchirappalli, Tamil Nadu, India.

Mrs.G.Nithya
Assistant Professor and Head,
Department of Computer Applications,
Kongu College of Arts and Science,
Karur, Tamil Nadu, India.

Mrs.A.Ahadha Parveen
Assistant Professor,
Department of Computer Science,
Lady Doak College,
Madurai, Tamil Nadu, India.

Mrs.B.Divya Prabha
Vice Principal & Head,
Department of Computer Science,
Sree Gokulam Public School,
Metro Sameera Garden,
Nenmeli, Chengalpattu, Tamil Nadu, India.

Published by

SK Research Group of Companies

The International Journal & Book - SKRGC Publication

142, Periyar Nagar, Madakulam
Madurai - 625003, Tamil Nadu, India

skrgc.publisher@gmail.com/+91 9790120237

https://skrgcpublication.org/isbn/

Title: BIG DATA FOR ANALYTICS

Author's Details: Dr.P.S.S.Akilashri
Ms.S.Thulasi Bharathi
Mrs.G.Nithya
Mrs.A.Ahadha Parveen
Mrs.B.Divya Prabha

Published by: SK Research Group of Companies,
Madurai - 625 003, Tamil Nadu, India.

Publisher's Address: 142, Periyar Nagar,
Madakulam, Madurai - 625 003,
Tamil Nadu, India.

Edition Details (I,II,III): I

ISBN: 978-93-95341-79-0

Month & Year June, 2022

Copyright © SK Research Group of Companies

Pages 190

Price ₹480/-

About the Authors



Dr.P.S.S.AKILASHRI is currently working as Associate Professor and Head in the PG & Research Department of Computer Science, National College (Autonomous), Trichy, Tamil Nadu, India. She has 19 years of teaching experience and produce 12 M.Phil Scholars and Ph.D Scholars, Presented papers in Conference, Published Journals and attended some FDP's and acted as an Examiner in some Universities.



Ms.S.Thulasi Bharathi is currently working as an Assistant Professor in the Department of Computer Science, St. Joseph's College (Autonomous), Tiruchirappalli, Tamil Nadu, India. She has 12 years of teaching experience and qualified UGC-NET 2 times with JRF once. The author has published 13 journals in Web of Science and UGC-CARE. Attended many Faculty Development programs, conferences, seminars and workshops, Acted as Resource person in many academic events. Now, currently doing PhD in the area of Multimodal Learning Analytics.



Mrs.G.Nithya is currently working as an Assistant Professor and Head of the Department of Computer Applications at Kongu College of Arts and Science, Karur, Tamil Nadu, India. She has completed an M.C.A. and an M.Phil. at Bharathidasan University, Tiruchirappalli. She started her teaching profession in 1995 and has 25 years of teaching experience. She has published many papers at International and National Conferences. Her paper was selected as the best paper at the international conference conducted at Srimathi Indira Gandhi College, Tiruchirappalli. She is interested in data structures and algorithms and has good knowledge of data analytics. She has been an Organizer, Mentor, and Coordinator at National and International Conferences, symposiums, and seminars. She has attended many Seminars, International Conferences, and Faculty Development Programs. She is a very good team leader and is able to work in any situation with good leadership qualities. She acted as a resource person during her career at many colleges.



Mrs.A.Ahadha Parveen is working as an Assistant Professor in the Department of Computer Science, Lady Doak College, Madurai, Tamil Nadu, India. She has completed her MCA., M.Phil., NET and currently pursuing her Ph.D from Bharathidasan University. She has more than 8 years of Teaching Experience. Her areas of interest include Big Data, Cloud Computing and Cryptography.



Mrs.B.Divya Prabha is a Research Scholar and currently working as Vice Principal & HOD Computer Science, Sree Gokulam Public School, Metro Sameera Garden, Nenmeli, Chengalpattu, Tamil Nadu, India. She has 12 years of Teaching Experience and presented paper in Conference, Published Paper in Scopus and attended some Seminars, Conference and Workshops.

Published by

SK Research Group of Companies

The International Journal & Book - SKRGC Publication

142, Periyar Nagar, Madakulam
Madurai - 625003, Tamil Nadu, India

skrgc.publisher@gmail.com/+91 9790120237

https://skrgcpublication.org/isbn/

SKRGC Publication
Read | Write | Teach

ISBN 978-93-95341-79-0

9 789395 341790

Department of Computer Science, IT & Computer Applications

of

SHRIMATI INDIRA GANDHI COLLEGE

Nationally Accredited at 'A' Grade (3rd Cycle)
by NAAC Tiruchirappalli 620 002

organizes

International Conference on Cloud Computing - Emerging Trends and Technologies

Venue:

Vidya Seva Ratnam
Shri K. Santhanam Auditorium

Date: 10.03.2023

Knowledge Partner

ICT ACADEMY

Conference Proceedings

TWO DAYS INTERNATIONAL CONFERENCE

ON

CLOUD COMPUTING – EMERGING TRENDS AND TECHOLOGIES

KNOWLEDGE PARTNER

ICTACADEMY

10th & 11th MARCH, 2023

DEPARTMENT OF COMPUTER SCIENCE, IT & COMPUTER APPLICATIONS

SHRIMATI INDIRA GANDHI COLLEGE

(Nationally Accredited at "A" Grade (3rd Cycle) by NAAC)

Tiruchirappalli – 620 002 Tamil Nadu, India.

Editors :

Ms. N. Vijayalakshmi,
IQAC Coordinator & Head,
Ms.V.Kiruthika,
Dr.M.Gomathy,
Asst. Professors in Computer Science, IT & Computer Applications,
Shrimati Indira Gandhi College, Trichy-2

ISBN: 978-93-93253-77-4

Publisher: Ryan Publishers
B-3, Lakshmi Pride, 80 feet road, 10th Cross West,
Thillai Nagar, Trichy- 620018, Tamil Nadu, India.
Website: www.ryanpublishers.co.in
Email: editor@ryanpublishers.co.in
Ph: +91 6374561101

Copyright © 2023 by Ryan Publishers

No part of this book shall be reproduced or transmitted in any form or by any means (electronic or mechanical including photocopy, recording, or any information storage or retrieval system) without the permission in writing of the publisher.

PARTICLE SWARM OPTIMIZATION BASED HYPER PARAMETER OPTIMIZATION TUNING USING ENSEMBLE BASED LEARNING MODELS FOR COVID 19 BINARY CLASSIFICATION

P.S.S.Akilashri[1], G.Nithya[2]

[1]Department of Computer Science, National College, Affiliated to Bharathidasan University, Tiruchirapalli, akilas27@gmail.com

[2]Department of Computer Science, National College, Affiliated to Bharathidasan University, Tiruchirapalli, nithya.gna@gmail.com

ABSTRACT

In decision making process applying advanced optimizing techniques and algorithms can improve the result. If the data analytics is applied in the health care industry, various advanced decision can be yielded. In recent years, covid 19 prediction has been a challenging area even after several medical improvements. The objective is to improve the prediction of covid 19, using classification algorithm. When the model did not yield the expected prediction/ outcome, then hyper parameter tuning techniques will play the key role to improve the efficiency of the model. Ensemble learning is a technique which creates multiple trees and combine them to produce improved results. There are various Ensemble Based Decision Tree models available, and each model has a set of hyper parameters. These parameters can be optimized using the optimizing algorithms. Particle Swarm Optimization is one such algorithm, where it optimizes the problem by iteratively trying to enhance a particle solution with respect to a measure of quality. In this proposed model, PSO is used for tuning of the hyper parameters such as Learning Rate, Max_Depth, N_Estimators of ensemble-based Decision Tree Algorithms like Random Forest, Gradient Boosting, Adaboosting and Extended Gradient Boosting. The best outcome was noted as 94% and 95% for gradient boosting and Extreme Gradient Boosting, respectively. This will be very much helpful for the health care community for binary classification of covid 19 prediction with 11 clinical features.

Keyword: Binary classifier, Hyper parameter, Particle Swarm Optimization, Ensemble models, covid, Confusion matrix.

1. INTRODUCTION

Classification problems in data analytics is a big challenge, as it required to predict a modelling problem where the class label is anticipated for a specific example of input data. In health care system, identifying a disease with clinical data is a well-known research area. Still, covid 19 [26] created so many big challenges for the entire world. Among many diseases, only certain diseases can be predicted using clinical data. Many classificational conventional models helped the researchers to predict the desired output. Lack of Training Data, Inclusion of unnecessary features, overfitting or underfitting the model causes increase in bias and variance in a prediction model and its essential to reduce this to build an efficient model. In every model, there are two types namely model parameters and Hyper parameters [13]. While training and executing, model parameters are assigned using inbuilt equations and function or assigned with default values which cannot be changed. But in the case of hyper parameters, it can be tuned manually. The hyper parameter values are assigned with default values or either through trial and error or through the experience shared by the other researchers. If we tune the parameters for the suitable model using optimization methods with proper dataset, that model will produce low bias and low variance, which improves the accuracy of the model. The optimization algorithm uses an objective function which either to be maximized or minimized according to the problem domain, which yields the optimized solutions and helps to improvise the model.

When the approach needs to increase the accuracy then Ensemble Based learning approach is suitable as per the literature for the binary classification. This approach does not depend on single model, as more than a model is created, and then combined to compute the final output. The combination is done using techniques like averaging or voting method, which again helps to increase the efficiency and ensure the model does not overfit the data. These Ensemble Based methods along with hyper parameter tuning will provide you the best possible solution for classification problems. Among bagging, stacking and boosting

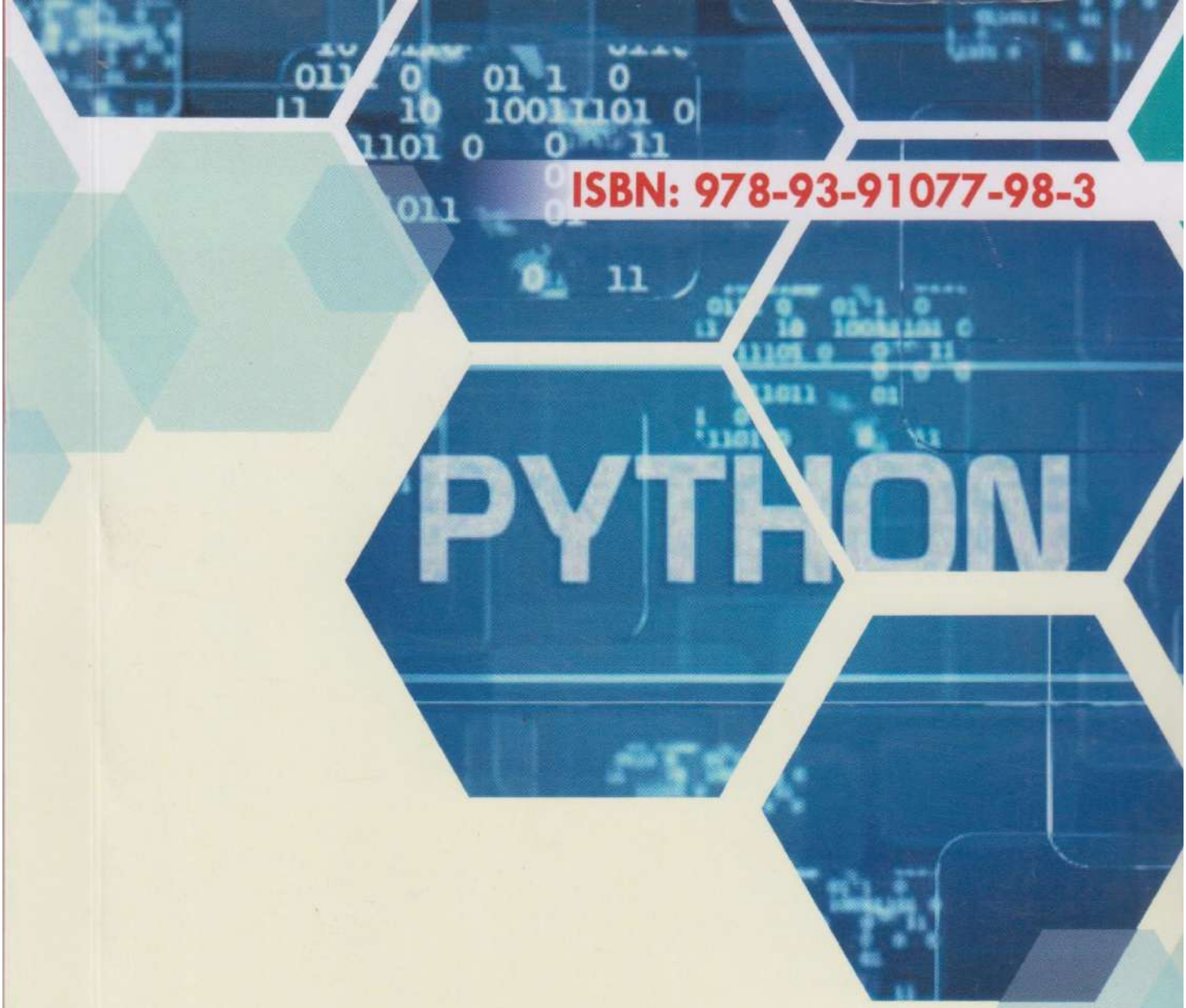
RYAN PUBLISHERS

B-3, LAKSHMI PRIDE,
80 FEET ROAD, 10TH CROSS WEST
THILLAINAGAR,
TIRUCHIRAPPALLI, 620018,
TAMIL NADU, INDIA
Email-contact@ryanpublishers.co.in
editor@ryanpublishers.co.in
website- www.ryanpublishers.co.in

ISBN 978-93-93253-77-4

Follow us on:-

ISBN: 978-93-91077-98-3



PROGRAMMING IN PYTHON

Dr. B. Chitradevi | Dr. V. Ramesh
Dr. P.S.S. Akilashri | Mrs. P. Shanthi
Mrs. P. Priyadharshini

PROGRAMMING IN PYTHON

Dr. B. Chitradevi
Assistant Professor,
Department of Computer Science,
Thanthai Hans Roever College (Autonomous),
Perambalur, Tamil Nadu, India.

Dr. V. Ramesh
Assistant Professor in the PG & Research,
Department of Mathematics,
Kandaswami Kandar's College,
Velur, Namakkal, Tamil Nadu, India.

Dr. P. S. S. Akilashri
Associate Professor and Head in the PG & Research,
Department of Computer Science,
National College (Autonomous),
Trichy, Tamil Nadu, India.

Mrs. P. Shanthi
Assistant Professor and Head,
Department of Computer Application,
Dr.S.Ramadoss Arts and Science College,
Periyavadavadi, Virudhachalam, Tamil Nadu, India.

Mrs. P. Priyadharshini
Assistant Professor,
Department of Computer Science,
Thanthai Hans Roever College (Autonomous),
Perambalur, Tamil Nadu, India.

Published by
SK Research Group of Companies
The International Journal & Book - SKRGC Publication
SKRGC Publication
Read | Write | Teach
142, Periyar Nagar, Madakulam,
Madurai 625003, Tamil Nadu, India
skrgc.publisher@gmail.com / +91 9790120237
https://skrgcpublication.org/isbn/

Title: **PROGRAMMING IN PYTHON**

Author's Name:
Dr. B. Chitradevi
Dr. V. Ramesh
Dr. P. S. S. Akilashri
Mrs. P. Shanthi
Mrs. P. Priyadharshini

Published by:
SK Research Group of Companies
SKRGC Publication
142 Periyar Nagar, Madakulam,
Madurai 625 003, Tamil Nadu India.

Reviewed by:
Dr.P.Vadivel Murugan
Assistant Professor
Department of Computer Science
Madurai Kamaraj University, Madura -02,
Tamil Nadu, India

Dr.M.Sathish Kumar
Assistant Professor
Department of Computer Science
Sourashtra College
Madurai 625004, Tamil Nadu India.

Printer's Details:
Shanlax Press,
66 T.P.K. Main Road,
Vasantha Nagar,
Madurai – 625003, Tamil Nadu, India

Edition Details (I,II,III): **I**

Month & Year: **November, 2022**

ISBN: **"978-93-91077-98-3"**

Copyright @ **SK Research Group of Companies**

Pages: **216**

Price: **₹350**

About the Authors



Dr.B.Chitradevi is currently working as Assistant Professor in the Department of Computer Science, Thanthai Hans Roever College (Autonomous), Perambalur(Dt). She has 19 years of teaching experience and Produced 6 IPR, 24 M.Phil Scholars, Published Book Chapters, 28 Journals Published in SCI, Scopus, Web of Science and UGC care, 29 Papers Presented in International and National Conference, 9 Papers Presented in Seminars, Attended many Faculty Development Programs, Workshops and Webinars. Acted as resource persons in many colleges, Reviewer and Editorial Member in some Peer reviewed Journals, received many Awards, Examiner in 9 universities and contribute her presence, Adjudicator in Jetlee Books of Records.



Dr. V. Ramesh is currently working as Assistant Professor in the PG & Research Department of Mathematics, Kandaswami Kandar's College, Velur, Namakkal(Dt). He has 6 years of teaching experience and hes published morethan 25 research publications (SCI/Scopus/UGC) in the International/National Journals. Presented 12 Research papers and received 3 awards.



Dr.P.S.S.Akilashri is currently working as Associate Professor and Head in the PG & Research Department of Computer Science, National College (Autonomous), Trichy(Dt). She has 18 years of teaching experience and Produce 12 M.Phil Scholars, Presented papers in Conference, Published Journals and attended some FDP's and acted as an Examiner in come University.



Mrs.P.Shanthi is currently working as Assistant Professor and Head in the Department of Computer Application, Dr.S.Ramadoss Arts and Science College, Viruthachalam, Cuddalore(Dt.). She has 16 years of teaching experience and cleared SET.



Mrs.P.Priyadharshini is currently working as Assistant Professor in the Department of Computer Science, Thanthai Perambalur(Dt.) Hans Roever College (Autonomous), Perambalur.

Published by

SK Research Group of Companies

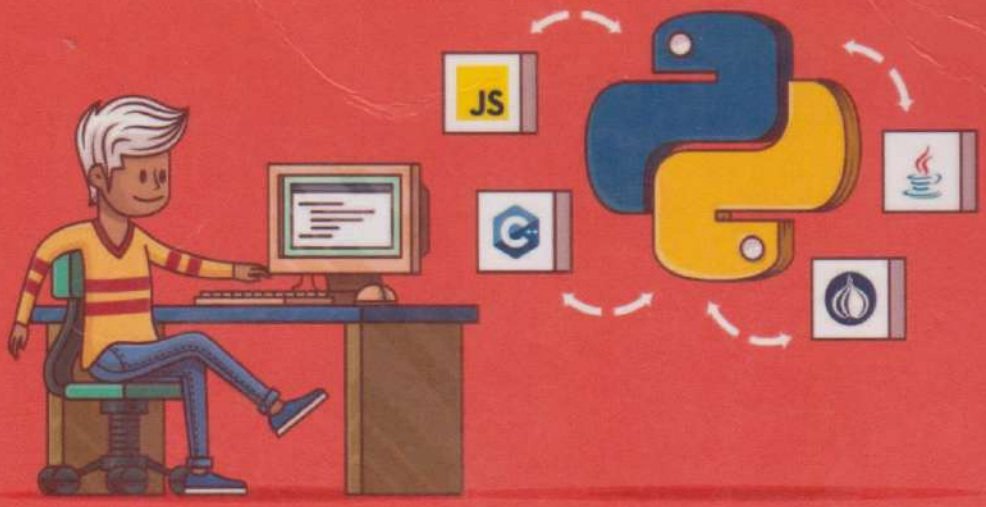
The International Journal & Book - SKRGC Publication

142, Periyar Nagar, Madakulam
Madurai - 625003, Tamil Nadu, India
skrgc.publisher@gmail.com/+91 9790120237
https://skrgcpublication.org/isbn/

SKRGC Publication
Read | Write | Touch

ISBN 978-93-91077-98-3

9 789391 077983



Python Programming

Dr. P.S.S. Akilashri
P. Sundari

NCT Lib
517.9
AKI
55012739

CHARULATHA PUBLICATIONS

June 2019

Price : **Rs.140/-**

ISBN No. : 978-93-89051-15-5



CHARULATHA PUBLICATIONS

New No.24, Thambiah Road,
West Mambalam, Chennai - 600 033.
Phone : 24745589, 24746546
Email : charulathapublication@yahoo.com
info@charulathapublications.com
www.charulathapublications.com

Python Programming

GT12739.
5,7.9 AK1

Dr. P.S.S. Akilashri, M.Sc., M.C.A., M.Phil., B.Ed., Ph.D.,
Vice-Principal
Head of Department of Computer Science,

P. Sundari, M.Sc.,M.Phil.,SET
Assistant Professor
Department of Computer Science
NATIONAL COLLEGE, Trichy.

NATIONAL COLLEGE
LIBRARY
TIRUCHIRAPALLI-1.

For online purchase
www.charulathapublications.com

THE FOLLOWING BOOKS FOR ARTS & SCIENCE

B.Sc., & BCA.	B.Com., & BBA.
Computer Graphics	Auditing Principles & Practices
Computer Organisation & Architecture	Advertisement & Sales Promotion
Computer Application in Business	Business Economics
Computer Networks	Business Communication
Digital Electronics & Microprocesor	Business Law
Data Mining and Data Warehousing	Business Environment
Database Management System	Business Regulatory Framework
Digital Computer Fundamentals & MP	Banking & Insurance Principle
Data Communication Network	Banking Theory Law & Practice
Design Analysis of Algorithm	Business Mathematics
Datastructures and Algorithm	Business Statistics
Fundamentals of Digital Computer	Business Organisation
HTML and Java Script	Corporate Accounting (I & II)
Information Technology	Cost Accounting (I & II)
Internet & its Application	Company Law and Secretarial Practice
Linux and Shell Programming	Consumer Behaviour
Multimedia	E- Commerce
Microprocessor & its Application	Entrepreurial Development
Object Oriented Analysis & Design	Environmental Studies
Operating Systems	Financial Accounting (I & II)
Programming in C	Financial Management
Programming in C++	Financial Management (MBA)
Programming in C++ & Datastructures	Financial Services
Programming in Java	Human Resource Management
Programming in C (Bsc-Maths Allied)	International Trade/Business
Programming in C & DS	Indirect Taxation
Python Programming	Insurance
Problem Solving Technique	Indian Economy
RDBMS & ORACLE	Lifeskill Education
RDBMS	Management Accounting
Resource Management Technique	Marketing Management
Software Testing	Management Concepts
Software Engineering	Operations Research
System Administration & Maintainance	Organisational Behaviour
Visual Programming	Principles of Management
Web Technology	Production Management
Soft Skill	Personality Development
Services Marketing	Research Methodology
SBAMM	Retail Management

CHARULATHA PUBLICATIONS

New No.24, Thambiah Road, West Mambalam, Chennai - 600 033.
Phone: 044-2474 5589, 044 - 2474 6546
Email: charulathapublication@yahoo.com / info@charulathapublications.com
FOR ONLINE PURCHASE
web: www.charulathapublications.com

ISBN-13: 978-93-89051-15-5
9 789389 051155

Editors
Dr. Suresh Frederick
Dr. Samuel Rufus

Contemporary Contemplations on New Literatures in English

Contemporary Contemplations on New Literatures in English

Editors

Dr. Suresh Frederick
Dr. Samuel Rufus

AUTHORS PRESS

Worldwide Circulation through Authorspress Global Network
First Published in 2020
by
Authorspress
Q-2A Hauz Khas Enclave, New Delhi-110 016 (India)
Phone: (0) 9818049852
E-mail: authorspressgroup@gmail.com
Website: www.authorspressbooks.com

Contemporary Contemplations on New Literatures in English
ISBN 978-93-89615-61-6

Copyright © 2020 Editors

Concerned authors are solely responsible for their views, opinions, policies, copyright infringement, legal action, penalty or loss of any kind regarding their articles. Neither the publisher nor the editors will be responsible for any penalty or loss of any kind if claimed in future. Contributing authors have no right to demand any royalty amount for their articles.

Printed in India at Thomson Press (India) Ltd.

Contents

Preface 5

PART I

1. The Phenomenon of Marginalised Otherness in Margaret Lawrence's *The Stone Angel* 15
D. E. Benet

2. Celebrating Indigenous Epistemologies: A Study of Margaret Atwood's *Survival: A Thematic Guide to Canadian Literature* 29
S. Samuel Rufus

3. Strategies of Native Resistance against Marginalisation: A Critical Study of Thomas King's *Medicine River* 41
K. Ravi

4. Re-Visioning the Politics of Gender(ed) Narratives in Canadian Children's Literature: Role Reversal and Gender Fluidity in Robert Munsch's *The Paper Bag Princess* 47
Divya Thyagarajan

5. Silhouettes, Silences and Voices of Women in Mordecai Richler's Select Novels 58
M. Mary Jayanthi

6. Coexistence as the Essence of Existence in Yann Martel's *Life of Pi* 72
Ancy Anita & R. Annie Karunya Bagyam

1

The Phenomenon of Marginalised Otherness in Margaret Lawrence's *The Stone Angel*

D. E. BENET

In a world where old age is regarded as a deviancy and a crisis and youth is thought of as the norm it is easy to discuss concepts like subjectivity and sexuality. Even the so called "sexual discourse" has as its focal point the life between menarche and menopause in a woman, and it fails to take into account the intervening period of life till finitude. In other words, as Simone de Beauvoir famously claims in her *The Coming of Age*, the elderly are "othered" by the society and marginalised in all substantive debates related to human life. If old age is a manner of being then it generates observable psychological traits and fairly visible bodily marks. Margaret Lawrence, the much acclaimed Canadian author of the Manawaka cycle of novels, presents in *The Stone Angel* (1964) the life history of a prairie woman named Hagar Shipley whose struggle for self-realisation closes with her death after she is well past her ninetieth year. The special note of interest for a reader here is her courage and pride which become bulwarks of support against the onslaught of time against her body and mind. Relatively free from religious faith and death anxiety Hagar is almost an existentialist who undergoes the Sartrian tension



Dr. Suresh Frederick, is an Associate Professor and UG Head in the Department of English, Bishop Heber College, Trichy, India, has 27 years of teaching experience at the college level. He is the Dean of IQAC. He has presented many papers in International and National conferences, published 114 articles in reputed books and journals and edited ten books. He holds a PhD in English from Bharathidasan University, India. He is the Vice-President of SELLTA (South Asian English Language And Literature Teachers Association), Vice-President of OSLE (Organization for Study of Literature and Environment), a Life Member of IASA (Indian Association for the Study of Australia), a Fellow of Eco-Ethics International Union (EEIU), a Member of The Andrew Marvell Society, a member of AsiaTEFL and an Associate Member of the Council for Research in Values and Philosophy. He has visited many foreign countries like Malaysia, Singapore, Thailand, Portugal and Ireland. The areas of his specialization are Ecocriticism, Mass Communication, ELT, Australian Literature, American Literature and British Drama. He has been awarded Editor's Choice Award for his Critical Writing by The Home of Letters (India) in 2010 and Best Research Paper award for Literature by Bishop Heber College in 2015.



Dr. Samuel Rufus started his career as Lecturer with the American College, Madurai, and later joined Madras Christian College as Assistant Professor, in the year 2003. His areas of interest are English Language Teaching, Soft Skills & Communication Skills, Postcolonial Studies, Literary Theory and Criticism.

Rufus has published six books - on Postcolonial Studies, UGC-NET Preparation for English Papers II & III, Soft Skills, Communication Skills, Canadian Literature, respectively. He is also the founder-Editor of the peer-reviewed biannual Journal *Eclectic Representations,* published by the Department of English, Madras Christian College, Chennai.

AUTHORS PRESS
Publishers of Creative & Scholarly Books

ISBN 978-93-89615-61-6

9 789389 615616

₹1200| $ 60

EDITED BY

P.K. SREEKUMAR

VINODKUMAR KALLOLICKAL

CONTEMPORARY HUMANITIES

AREAS AND APPROACHES

CONTEMPORARY HUMANITIES

AREAS AND APPROACHES

Edited by
P.K. SREEKUMAR
VINODKUMAR KALLOLICKAL

Contemporary Humanities: Areas and Approaches

Edited by: P.K. Sreekumar & Vinodkumar Kallolickal

@ All right reserved.

No part of this publication may be reproduced in any manner without the prior written consent of the publisher.

South Zone Books
Ernakulam, Kadavanthara
Kochi, Pin - 682020
For Copies : 97461 79123

First published November 2020
Number of copies: 500
Printing: Orchids Kothamangalam

ISBN : 978-81-922314-8-8

Price Rs 180/-

Contents

Introduction 5-14

Multi-Method Fieldwork in Practice: Colonial Legacies and Ethnic Conflict in India 15-25

Smoking in India: Causes, Correlations and Patterns 26-35

Reading Texts and Traditions:
The Ambedkar-Gandhi Debate 36-68

Gandhi and Narayana Guru on the Question of Reform:
Exploring the Conflicting Cartographies of Modernity 69-88

An Order of Kinglessness:
Political Authority and Power in North Malabar
Oral Poems 89-129

A Thousand Years of Africans in India:
The Siddis of Karnataka 130-149

Sherlock Holmes and /as the Locus of Colonial Cognitive Construction 150-156

Mapping the Memory: Historicity in the
Writing of Memoir 157-168

As religious self I touch you even before
I proclaim it in Faith- Levinas answers Zizek 169-175

A Narratological Analysis of J. D. Salinger's
The Catcher in the Ry 176-184

Kerala Industry Threading New Heights:
An Overview of Select Initiatives and Strategies 185-202

ERP Implementation:
A Conceptual Analysis of the Critical Success Factors 203-216

The multidisciplinary anthology *Contemporary Humanities: Areas and Approaches* is a composite and comprehensive look at the timeline and trajectories that the subjects subsumed under the broad label of 'humanities' have recently traversed. Through twelve research papers contributed by teachers and researchers hailing from as many as seven different subjects, it revisits and interrogates some of the more nuanced aspects of the current social structures, conventional wisdom and zeitgeist. Written in lucid language with apposite terminology, the book elaborately and theoretically discusses a wide spectrum of concerns relating to methodology, conceptual categories, statistical tools, national debates, dialectical engagements, literary expressions, indigenous oral poems, economic interventions and emerging business models. It guides aspiring research scholars to the avenues of the age and provides them with epistemological blueprints as to how to best carry out productive investigations with a view to expanding the existing repository of knowledge.

P.K. SREEKUMAR is Assistant Professor of English and Research supervisor at Maharaja's College, Ernakulam. He regularly writes research papers and popular articles in both Malayalam and English. His books include *Stopping by Woods on a Snowy Evening, Literary Theory for Students and Sins and Shadows.*

VINODKUMAR KALLOLICKAL is Associate Professor of History and Research supervisor at Maharaja's College, Ernakulam. His publications include Concerns, Issues and Perspectives in *History,Science and Society, Addressing History and Annavicha-*

South Zone Books
Ernakulam, Kadavanthra
Kochi - 20, Pin:- 682 020
southzonebooks@gmail.com

Price ₹ :180.00

9 788192 231488

ISBN: 978-81-922314-8-8

Critical Voices

South Asian History, Culture and Literature



Editors
D. E. Benet
S. Samuel Rufus

Critical Voices

South Asian History, Culture and Literature

Editors

D. E. Benet
S. Samuel Rufus

WINNERMAN PUBLICATIONS PRIVATE LTD

First Published: **December 2016**

ISBN: 978-81-931937-0-9

© **Dr. D. E. Benet & Dr. S. Samuel Rufus**

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means – electronic, mechanical, photocopying, recording or otherwise – without the prior permission of the publisher.

Published by

WINNERMAN PUBLICATIONS PRIVATE LTD.,
III Block, Mogappair West, Chennai – 600 037
Email: winnermanpublishers@gmail.com

Printed at
The Printing House
6 Race Course Road, Khajamalai
Tiruchirappalli 620023

Contents

Preface

1. Water - The Universal Solvent as a Rectifier in Anita Nair's *Ladies Coupe'*
   - D. Leema Davidson 11

2. The Ganga – A Victim of Politics and Pollution: A Study on Aravind Adiga's *The White Tiger*
   - K. Thangaraj 17

3. Negotiating Ethnicity in the Select Novels of Chitra Banerjee Divakaruni
   - Gunjan Agarwal & Gunjan Kapil 23

4. (Hi)Stories from the Emergency: Reading Rohinton Mistry's *A Fine Balance*
   - Mabel Susan 33

5. Revisiting the Traumas of Partition in Manto's Life and Works across the India-Pakistan Divide: A Socio-Historico-Political Perspective
   - Nanzie Antony Raj 41

6. The Relevance, Style, Timelessness and Allure of R K Narayan and His Works
   - M. Pradeep Raj & S. Nagendrakumar 49

7. Subversion and Resistance to Power in Khaled Hosseini's *A Thousand Splendid Suns*
   - Annie Vimala 53

8. Women in the Virtual World: A Feminist Outlook
   - Mamatha V Freeman 57

9. Sufferings of an Indian Expatriate in Bharathi Mukherjee's *The Tiger's Daughter*
   - P. Priya 67



ISBN 978-81-931937-0-9

9 788193 193709

Published by
WINNERMAN PUBLICATIONS PRIVATE LTD.,
III Block, Mogappair West, Chennai – 600 037

Printed @ The Printing House, Try-23. Ph : 0431-2420121

Ecocriticism

Paradigms and Praxis

Dr.Suresh Frederick

NCBH

Ecocriticism

Paradigms and Praxis

Dr. Suresh Frederick

New Century Book House (P) Ltd.,
41-B, SIDCO Industrial Estate,
Ambattur, Chennai - 600 050.
☎: 044-26251968, 26258410, 48601884

Language: English

Ecocriticism Paradigms and Praxis

Author: **Suresh Frederick**

First Edition : December, 2019

Copyright : Publisher

No. of pages : iv + 194 = 198

Publisher:

New Century Book House Pvt. Ltd.,

41-B, SIDCO Industrial Estate,
Ambattur, Chennai - 600 050.
Tamilnadu State, India.
Email : info@ncbh.in
Online : www.ncbhpublisher.in

ISBN: 978 - 81 - 2343 - 945 - 7

Code No. A 4298

₹ 170/-

Branches

Ambattur (H.O.) 044 - 26359906 **Spenzer Plaza (Chennai)** 044-28490027
Trichy 0431-2700885 **Pudukkottai** 04322- 227773 **Tanjore** 04362-231371
Tirunelveli 0462-4210990, 2323990 **Madurai** 0452 2344106, 4374106
Dindigul 0451-2432172 **Coimbatore** 0422-2380554 **Erode** 0424-2256667
Salem 0427-2450817 **Hosur** 04344-245726 **Krishnagiri** 0434-3234387
Ooty 0423 2441743 **Vellore** 0416-2234495 **Villupuram** 04146-227800
Pondicherry 0413-2280101 **Nagarcoil** 04652-234990

Printed at:

Pavai Printers (P) Ltd.,

16 (142), Jani Jan Khan Road, Royapettah, Chennai - 14
☎: 044-28482441

All rights reserved. No part of this book may be reprinted or reproduced or utilised in any form or by any electronic, mechanical, or other means, now known or hereafter invented, including photocopying and recording, or in any information storage or retrieval system, without permission in writing from the publishers.

CONTENTS

1. Green Glimpses: An Introduction to Ecocriticism 1
Dr. Suresh Frederick

2. Literature and Ecology: An Experiment in Ecocriticism 14
William Rueckert

3. A Fable for Tomorrow (From Silent Spring) 31
Rachel Carson

4. The Obligation to Endure (From Silent Spring) 33
Rachel Carson

5. Ecocriticism: The Nature of Nature in Literary Theory and Practice 40
Michael Branch

6. Some Principles of Ecocriticism 57
William Howarth

7. Revaluing Nature: Toward An Ecological Criticism 79
Glen A. Love

8. A Theological Response to the Ecological Crisis 94
Rev.K.C.Abraham, Ph.D.

9. Ecofeminist Literary Criticism 112
Gretchen T. Legler

10. An Introduction to Neo-tinai Poetics 124
Nirmal Selvamony

11. Glossary 139
Compiled by: D.E.Benet

Poems for Study

1. The Tame Bird 178
Rabindranath Tagor

2. Our Casuarina Tree 179
Toru Dutt



DR. SURESH FREDERICK, is an Associate Professor and UG Head in the Department of English, Bishop Heber College, Trichy, India, has 27 years of teaching experience at the college level. He is the Dean of IQAC. He has presented many papers in International and National conferences, published 114 articles in reputed books and journals and edited ten books. He holds a PhD in English from Bharathidasan University, India. He is the Vice-President of SELLTA (South Asian English Language And Literature Teachers Association), Vice-President of OSLE (Organization for Study of Literature and Environment), a Life Member of IASA (Indian Association for the Study of Australia), a Fellow of Eco-Ethics International Union (EEIU), a Member of The Andrew Marvell Society, a member of Asia TEFL and an Associate Member of the Council for Research in Values and Philosophy. He has visited many foreign countries like Malaysia, Singapore, Thailand, Portugal and Ireland. The areas of his specialization are Ecocriticism, Mass Communication, ELT, Australian Literature, American Literature and British Drama. He has been awarded Editor's Choice Award for his Critical Writing by The Home of Letters (India) in 2010 and Best Research Paper award for Literature by Bishop Heber College in 2015.

ISBN 978-81-2343-945-7

New Century Book House (P) Ltd.,

41-B, SIDCO Industrial Estate,
Ambattur, Chennai - 600 050
☎ 044 - 26251968, 26258410, 48601884
www.ncbhpublisher.in | email: info@ncbh.in

9 788123 439457

Code No. A 4298 ₹ 170/-

99): 35-42; *"kaḷam as Heterotopia."* Folklore as Discourse.
raswamy. Chennai: National Folklore Support Centre, 2006.
"Modern Womanhood: A New Caste?" *A Vision for*
R. Gopalan. ceṉṉai: Madras Christian College, 1984, 28-34.
"Ecorights and Responsibility." *New Horizons of*
i. New Delhi: Studera Press, 2015, 481-505.
State and Society in Medieval South India. Delhi: Oxford
South Indian Temple Inscriptions, vol. III, Part II.
iental
brary, 1957.
e III. Madras: University of Madras, rpt., 1982.
ppaṭai (Guide to Nature). putuccēri: vāṉakap patippakam,
a cōkam (Just a little bit sadness). Tuticorin: S.P.R.Books,

Glossary

Compiled by: D.E.Benet

abandoned village A village that has been abandoned due to plague/ famine / war or climatic changes. See triggering town.

abstract individualism It is a view in philosophy about solitary, separate, unrelated, atomistic selves far removed from the social contexts and relationships in which they find themselves. In contrast to this view, ecofeminists perceive humans as socially embedded, relational selves and not abstract selves. See ecofeminism

acid rain Deposition of acidic components in rain, snow, fog, dew, or dry particles is commonly referred to as acid rain and accurately as 'acid precipitation'. It is neither a simple nor a single phenomenon. The acid gases sulphur dioxide (SO_2) and oxides of nitrogen (NO_x) are produced by burning fossil fuels. Incomplete combustion of these fuels releases hydrocarbons. These may have effects as dry gases or they may be washed out of the atmosphere to produce acid precipitation in rainfall and snow. Acid rainfall is often accompanied by major changes in ecosystems and damage to buildings. The most industrialized areas of the world, such as eastern USA, western Europe, north-east China and Japan, have all experienced rainfall with pH well below 4.0 (pH 5 is the conventionally accepted lower limit for the natural rainfall acidity). The acidity and alkalinity of a liquid medium is often expressed in pH values. Neutral pH of 7, Acid pH of less than 7 and alkaline pH of greater than 7. The remedy lies in reducing the release of pollutant gases. The desulphurization technology is available and it is effective in mitigating the acid rain problem.

affordances They are defined as a relation of possibility between animals and their environment. J. Gibson in *The Ecological Approach to Visual Perception* (1979) defines affordances as what an environment offers, provides or furnishes to an animal. Affordances are possible when a person is in tune with the environment. Gibson states that the perception of the world is to co-perceive oneself. The phrase 'co-perceive' oneself means that a perception of the other or something is possible only as it relates to us. At the primordial level, affordance is perceived and acted upon directly. For example, the mother's breast affords nourishment directly to the child without needing either explanation or representation.

afforestation It is the planting of trees either for commercial or non-commercial purposes. For the commercial purpose, trees are often selected on the basis of their commercial value and planted. On the other hand, for the non-commercial purpose, trees are selected on the basis of their rarity or scientific value and planted. This differs from reforestation which is the restocking of existing forests and woodlands which have been denuded. In the commercial afforestation programme, wetlands and grasslands are often selected for planting of trees and this in turn affects the wetland and grassland ecosystem. Afforestation is also as dangerous as climate change if it is not done in a scientific way.

See also forest, deforestation and aranyakas.

agroecology A science that applies ecological concepts and principles to the design, development and management of sustainable agricultural system. It studies ecological phenomena such as predator/ prey relation or crop / weed competition in

Humour Traditions in Australia and Canada



B Hariharan
Suja Kurup PL

Humour Traditions in Australia and Canada

Edited by

B. Hariharan

and

Suja Kurup P.L.

EMERALD
PUBLISHERS

Humour Traditions in Australia and Canada •Author: B. Hariharan & Suja Kurup P. L. • © Emerald Publishers, 2020 • First Print : 2020 • Size : 1/8 Demy •Page No : 272 • Language : English •Publisher: Olivannan Gopalakrishnan, Emerald Publishers, 15A, First Floor, Casa Major Road, Egmore, Chennai – 600 008.

☎ : +91 44 28193206, 42146994 | ✉ : info@emeraldpublishers.com
: www.emeraldpublishers.com

No part of this book may be reproduced in any written, electronic, recording, or photocopying without written permission of the publisher or author. The exception would be in the case of brief quotations embodied in the critical articles or reviews and pages where permission is specifically granted by the publisher or author.

Although every precaution has been taken to verify the accuracy of the information contained herein, the author and publisher assume no responsibility for any errors or omissions. No liability is assumed for damages that may result from the use of information contained within.

Price: ₹ **350.00**

ISBN: 9789389080735

Printed at: Aruna Enterprises, Chennai.

Contents

Introduction - 01
B. Hariharan and Suja Kurup P.L.

1. The Comic Imagination: A Historical View - 10
Dr. D.E. Benet

2. Humour in Canadian Writings: A Brief Overview - 24
Dr. K. Reshmi

3. The Maple Laughs Forever, but who will Hear? A Foray into the Locations of Humour in Canadian Poetry - 34
Dr. Ravishankar Rao

4. Ridiculing Conquistadors: Humour as a Weapon in Aboriginal Writings - 46
Dr. Susan Alexander

5. "With the Tongue-in Cheek" – Foraying into the Indigenous Landscapes of Australia through the Select Poems of Les Murray - 59
Dr. Nisha Mathew

6. Dancing with the *Weesaygeechak*: De-coding Indigenous 'humour' in the Performance Texts of Indigenous Artists in Canada - 72
Dr. Dheeman Bhattacharya

7. Comic Subversion through the Trickster: Reading Thomas King's Short Stories - 83
Dr. Abida Farooqui

8. Laughter in Resistance: Humour Traditions in Select Aboriginal Women's Writing - 99
Sangeetha V. and Anju Devadas R.D.

9. Portrait of an Urban Indian: An Analysis of Humour in the Stories of Richard Wagamese - 111
Rinu Krishna K.

10. Laughing their Heads off: The Disruptive Comedy of Queer Stand-up - *Nanette* - 125
Dr. Sonya J. Nair

11. The Politics of Representation of Canada in Select American TV Shows - 138
V.K. Krishnakumar and Sanju Sudarsan

12. Humour in Context: Exploring the Culture Code in *Superwog* - 152
Dr. Priyanka M.C.

13. "I Must Quit Comedy": The Role of *Nanette* in Exploring the Limits of Stand-up Comedy - 165
Ann Christina Pereira and Dr. Sarika Tyagi

14. Adulthood and Televised Australian Humour: Reading *Please Like Me* - 175
Anusha A.J.

Humour speaks the language of exaggeration and it is at the same time serious business. It is also serious business to discuss the ways in which cultures have claimed such traditions and explore how humorous narratives address our lived and living exaggerations. The present volume of essays focuses on some of the facets in the humour traditions in Australia and Canada. Certainly, the expression and experience of humour in Australia and Canada has a profound social and political dimension. This is why it is important to explore this genre in our times. A collection of essays on the humour traditions in Australia and Canada will perhaps bring more than a smile and make us ask how and why we laugh the way we do.

The Editors

Dr. B. Hariharan is Professor at the Institute of English and is also Director of the Centre for Canadian Studies, University of Kerala, Thiruvananthapuram, Kerala

Dr. Suja Kurup P.L. is Professor at the Institute of English and is also Director of the Centre for Australian Studies, University of Kerala, Thiruvananthapuram, Kerala

ISBN 978-93-89080-73-5

9 789389 080735

EMERALD PUBLISHERS

₹ 350/-

EMERALD PUBLISHERS
15A, I Floor, Casa Major Road, Egmore,
Chennai 600 008. Ph: 044 - 28193206, 42146994
Mail: info@emeraldpublishers.com
Web: www.emeraldpublishers.com

Literature as Cultural Artefact

Theoretical Approaches to Reading Texts



Edited by

V. S. Joseph Albert

D. Jockim

S. Aloysius Albert

Published by

Research Department of English and
Folklore Resources & Research Centre
Palayamkottai—627002
Tamil Nadu, India

Literature as Cultural Artefact

Theoretical Approaches to Reading Texts

Edited by
V. S. Joseph Albert
D. Jockim
S. Aloysius Albert

Published by
Research Department of English and
Folklore Resources & Research Centre
St. Xavier's College (Autonomous)
Palayamkottai—627002
Tamil Nadu, India

Published by
Research Department of English and
Folklore Resources & Research Centre
St. Xavier's College (Autonomous)
Palayamkottai—627002 Tamil Nadu, India

ISBN 81-87905-13-1
First published 2020
© St. Xavier's College (Autonomous), Palayamkottai

Advisory Board
Dr. P. P. Ajaya Kumar, Pro-Vice Chancellor, Professor of English & Former Director, Institute of Distance Education, University of Kerala
Dr. A. S. Dasan, Professor of English and Director, Shukrodaya's Academy for HRD, & Former Chairman, Dept. of English, University of Mysore
Dr. A. Joseph Dorairaj, Professor of English & Dean, Gandhigram Rural Institute—Deemed University
Dr. Predeep Trikha, Professor of English, Mohanlal Sukhadia University, Udaipur, Rajasthan
Dr. N. Ramachandran, Director, Folklore Resources & Research Centre(FRRC),St. Xavier's College, Palayamkottai
Dr. R. Jeya Sundararaj, Associate Professor & Head, Dept. of English, St. John's College, Palayamkottai

Edited by
Dr. V. S. Joseph Albert, Deputy Principal & Associate Professor of English, St. Xavier's College, Palayamkottai
Dr. D. Jockim, Asst. Professor of English, St. Xavier's College, Palayamkottai
Dr. S. Aloysius Albert, Asst. Professor of English, St. Xavier's College, Palayamkottai

All rights reserved.

Rs. 600

Printed at Muthuletchumi Press, Palayamkottai

CONTENTS

Page

Editorial 12

Reading as Historicizing: Bakhtinian and Indic Approaches to Hermeneutics 18
Dr. A. S. Dasan

The Aesthetics of Popular Culture 45
Dr. D. E. Benet

License to Kill: Normalization of Culture of Violence by the Modern Media 51
Dr. V. Christopher Ramesh

The Role of Intellectuals: Apropos Antonio Gramsci, Julien Benda and Edward Said 58
Dr. J. Ragu Antony

Literary Theories as Interpretations of Cultural and Collective Consciousness 66
Dr. S. Sudha Rani

'The Rest Is Silence': A Cultural Studies Approach toTeaching Shakespeare 78
Dr. V. S. Joseph Albert

Epistemological Tension in the Narration of Myth: A Reading of Amitav Ghosh's *Gun Island* 89
Dr. Lizie Williams

A Metaphorical Representation of Postcolonial Nigeria in Chigozie Obioma's*The Fishermen* 98
Dr. L. Judith Sophia

Literature as Cultural Artefact

Theoretical Approaches to Reading Texts

Ed. V. S. Joseph Albert, D. Jockim and S. Aloysius Albert

Literature is primarily a cultural artefact. Literary connection cannot take place in isolation from social and political context, as explained by Frederic Jameson in The Political Unconscious. Human beings are basically biological, psychological, social, cultural, historical and spatial beings in temporality. Literary texts always testify these experiences in a certain space. Literature unlocks the hidden dreams and discovers the covered desires of humans to make their voice heard to the rest of the humanity.

It is true that our interpretation of literary texts has changed after reading Alan Sinfield's analysis of Tennyson's "Ulysses," Stephen Greenblatt's study of Shakespeare's Hamlet and John McLeod's comments on Charlotte Bronte's Jane Eyre. We are in favour of multiple perspectives, which, in a sense, will increase the suggestiveness and complexity of literature especially in a country like India with its multicultural, multilingual and multi-religious structure. The research papers in this book deal with the following themes:

- Literature and Society (Cultural Materialism)
- Literature and History (New Historicism)
- Cultural Identity and Diaspora
- Postcolonial Studies
- The Idea of Nation in Relation to Culture
- Gender Studies
- Language and Culture
- Theorizing Multiculturalism
- Ecology and Literary Production
- Media and Socio-Cultural Formations
- Anthropological and Ritual Sub-Texts

Published by

Research Department of English and
Folklore Resources & Research Centre
Palayamkottai—627002
Tamil Nadu, India

ISBN 81-87905-13-1



NET. SET.. GO...!

NTA-UGC-NET/JRF/SET

English

- Solved NET Papers
- Preparatory Tests
- Study Material
- Question Bank

Dr. D. E. Benet
Dr. S. Samuel Rufus

Revised & Updated

© D. E. Benet & S. Samuel Rufus

First Edition : August 2014
Second Edition : March 2015
Third Edition : August 2017
Fourth Edition : June 2021

ISBN : 978-81-953137-0-9

Price : 920/-

Published by : JAZYM PUBLICATIONS
Trichy - 620 023.

Printed at : THE PRINTING HOUSE
6, Race Course Road, Trichy -23.
✆ 0431-2420121 / 94435 87233

The authors of this book have taken all possible effort to ensure that the contents of the book do not violate any existing copyright or other intellectual property rights of any person in any manner whatsoever. Due care has been taken to acknowledge all our sources (both print and online) as and where necessary. If any copyright has been inadvertently infringed, the same may be brought to the notice of the authors in writing for corrective action at peaceeben@gmail.com OR rufusonline@gmail.com

REVISED, UPDATED & ENLARGED

NTA - UGC-NET/JRF/SET

NET. SET.. GO...!

English

Paper II

SOLVED & EXTENSIVELY ANALYSED
PREVIOUS YEARS' QUESTION PAPERS

OOO

STUDY MATERIAL

OOO

QUESTION BANK

OOO

PREPARATORY TESTS

Dr. D. E. Benet

Dr. S. Samuel Rufus

To brew the perfect cup of coffee, one needs to select the best coffee beans! Indeed the best of the best has been carefully handpicked by two renowned teachers of English, who have also cleared their UGC-NET and bagged the coveted Junior Research Fellowship. For more than a decade now they have been imparting foundational knowledge of English Studies to hundreds of students in their respective colleges and beyond. Regarding themselves as 'teachers without frontiers,' they have helped a sizable number of students to clear their NET. This book is an arduous compilation of questions and answers and study material.

Dr. D. E. Benet teaches English at National College (Autonomous), Tiruchirapalli, since 1996. He began his career at Regional Institute of English, Bengaluru and served as a lecturer for six years at Islamiah College, Vaniyambadi, before migrating to Tiruchirappalli. He has been guiding both M.Phil and PhD scholars for many years now. He has presented scholarly papers in more than fifty national and international seminars and conferences. Besides he has published fourteen papers in national and international journals, and anthologies. He has three books to his credit as well. He continues to be a resource person to Human Resource Development centre of various Universities. He is a motivational speaker and hopes to train a good number of students and scholars who will one day become creative writers and translators. He has abiding passion for reading literary fiction and wants to read at least one book by every Nobel Prize winner in literature.

Dr. S. Samuel Rufus started his career as Lecturer with the American College, Madurai, and later joined Madras Christian College as Assistant Professor, in the year 2003. His areas of interest are Soft Skills & Communication Skills, Postcolonial Studies, Literary Theory, and Criticism. Rufus is the Recipient of the University Gold Medal in MA English and Winner of the President Venkataraman Gold Medal for Academic Excellence, Bharathidasan University, Tiruchirappalli, Tamil Nadu, 2002. He has authored three books, on Postcolonial Studies, Communication Skills and Soft Skills, respectively. Besides having presented papers in more than forty national and international seminars and conferences, he has edited many scholarly books and journals on various subjects. He is also the founder-Editor of the peer-reviewed biannual Journal *Eclectic Representations*, published by the Department of English, Madras Christian College, Chennai.

₹920

PJ JAZYM PUBLICATIONS
No.1, Post Office Street
Khajamalai, Trichy - 23
Tamil Nadu
Mobile : 94435 87233
Email : jazymtrichy@gmail.com

ISBN 978-81-953137-0-9
9 788195 313709

Printed @ The Printing House, Try-23. Ph : 0431-2420121

POEMS APLENTY

A CHOICE OF VERSE

Edited by
Dr.G. Venkatraman
Dr.S. Ganesan



LITERARY SCHOLARS SOCIETY
INDIAN UNIVERSITIES PRESS

POETRY

POEMS APLENTY

A Choice of Verse

Edited by

Dr. G. Venkatraman

Dr. S. Ganesan

Literary Scholars Society

INDIAN
UNIVERSITIES PRESS

POEMS APLENTY
A Choice of Verse

Edited by
Dr. G. Venkatraman
Dr. S. Ganesan

First Published: September, 2021

© Literary Scholars Society, Thanjavur 2021

Published by

INDIAN
UNIVERSITIES PRESS

INDIAN UNIVERSITIES PRESS
Imprint of Bharathi Puthakalayam
7, Elango Salai, Teynampet, Chennai - 600 018
044 -24332424, 24332924, 24339024
Email: thamizhbooks@gmail.com | www.thamizhbooks.com

Rs. 200/-
Printed at Printech India, Chennai - 600 005.

CONTENTS

Gracias III
Preface V
Dedication IX

1. *Anita Nair*
   In Which A Small Gesture Becomes 1
2. *S.A. Sankaranarayanan*
   DNA of Poetry 5
   Romantic Imagination's Kid! 8
3. *Padma Shri Dr. Y.S. Rajan*
   NASA Satellite ATS 11
   2011 13
4. *Palani Arangasamy*
   Culture of the Tamils 15
   The Birth of Man 16
5. *Noel Joseph Irudayaraj*
   Brainless Fate 17
   Thirteen Ways of Looking at a Goatee 18
6. *C. Muralidara Kannan*
   Oh, Withered Humanity! 20
   Where else can I seek enlightenment? 22
7. *Cardiologist Dr. S. Elangovan*
   Lake-View Ficus Tree and Me 23
8. *Kalaimaamani Sasirekha Balasubramanian*
   Naatyam - The Diritta Via! 27
9. *G. Venkatraman*
   Terpsichore in Tanjore! 29

These poems belong to a lot of unknowns. Poetry read, learnt, taught, recalled, reflected, wake poetry up, not just to one kind, but fundamentally. Poems come from the inner valley of the house of this delta zone where they grow up looking identical to other zones they sprout up in. When talents of larger Thanjavur started writing for the Literary Scholars Society (LSS), the idea that they might get published was a fantasy. Nor did their fans boast of any distinct literary pedigree. Though it all still felt like a closed establishment, seeds sprouted on their own count.

As they reflect, they suppose, they on others behalf, always think and pen, pen and think, till the nib turns impatient to perforate the paper. Fantasy rallies with fans! Every stroke of pen, a limper of a line, deserves medal of a note, a short note, at least a three letter SMS! It is said a fig tree watching another bears fruit! Poetic laurel flowers likewise. Every poem says it seems, "Here next is my success, and here I am!"

Despite the profile fixture of the poems here, LSS is keen to stress their involuntary status! "Keep your distance, O, Elite London or Stratford" We too find our Grassmere when Rains lash our Cauvery banks! We are in a world of Zooms! From terraced house to neighbouring galaxy, from Besant Hall to Lawley's, everything for talents young is a spark plug! They are clouds, they are cuckoos, they are no brows, no high faultin! Prompt, diligent, fearless lifeline with no deadline! All hands are obsessive Smiths! All are spoken words and electronica too!

If poetry be "go anywhere art form," this Plenty is an out of the blue modus operandi. And a retrospective education, walking round their own homes a few minutes thinking of queue of invites for them to go the way back to Kamban or Elango, Valmeeki or Homer! No critical heffalump traps can scare the mammoth of the thought the LSS explores. "Poems Aplenty" shall come out in series with talents queued up to claim honours, we fervently hope.

2058279

₹ 200/-

INDIAN UNIVERSITIES PRESS

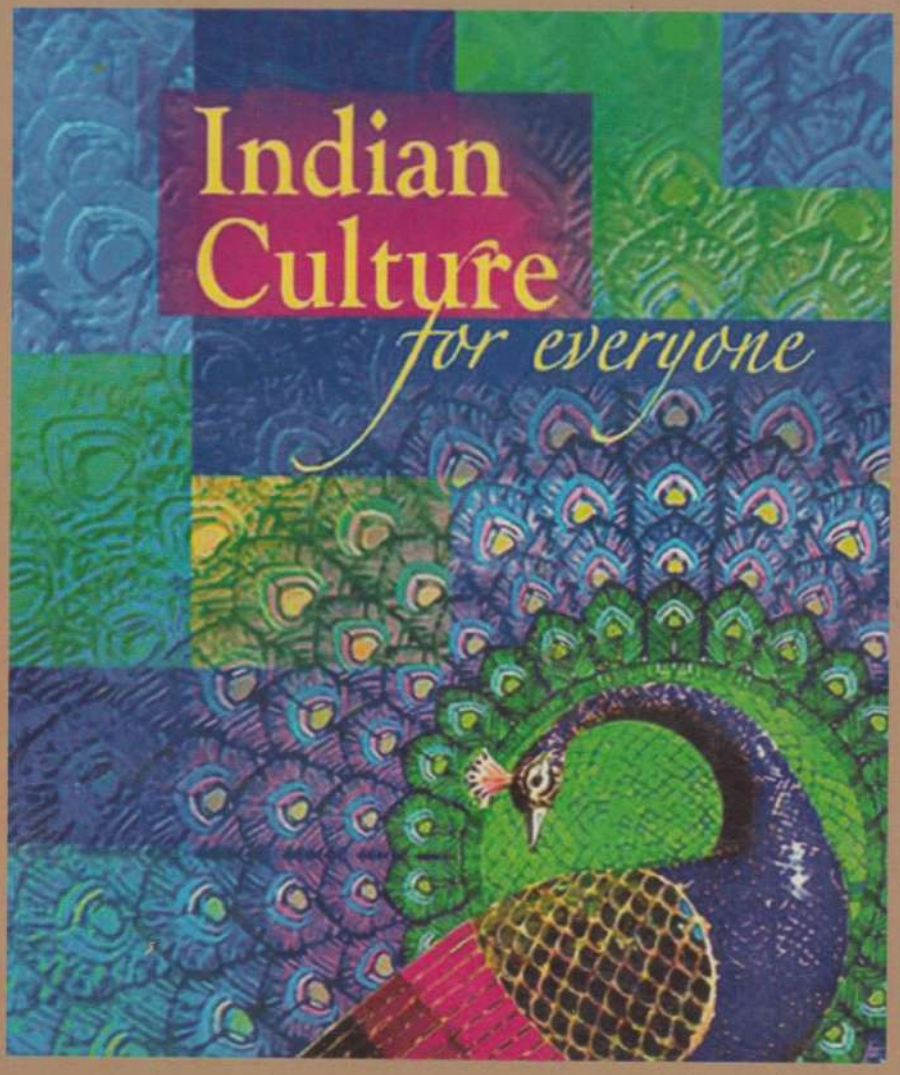
Literature Matters

Literary Scholars Society

ISBN 978-93-91262-81-5

9 789391 262815 01

INDIAN CULTURE IN INDIAN ENGLISH LITERATURE



Dr. R. ELAVARASU

Proceedings of the
National Seminar on

INDIAN CULTURE IN INDIAN ENGLISH LITERATURE

January 8 - 9, 2015

Edited by

Dr. R. ELAVARASU
Associate Professor and Head
Department of English
National College, Trichy-1

NATHI PUBLICATIONS
1271A, Sulthanjiappa Lane, South Rampart,
Thanjavur-613 001, Tamil Nadu, India.

Proceedings of the National Seminar on
INDIAN CULTURE IN INDIAN ENGLISH LITERATURE
on 8-9 January 2015

Subject: Indian Culture in English

Editor: Dr. R. Elavarasu

First Edition: January 2015

Pages: 174

Wrapper Design and Laser: Nagu Computers, Thanjavur.
Phone: 04362-238729.

Printing: BHARATHI OFFSET PRINTERS,
Thanjavur.

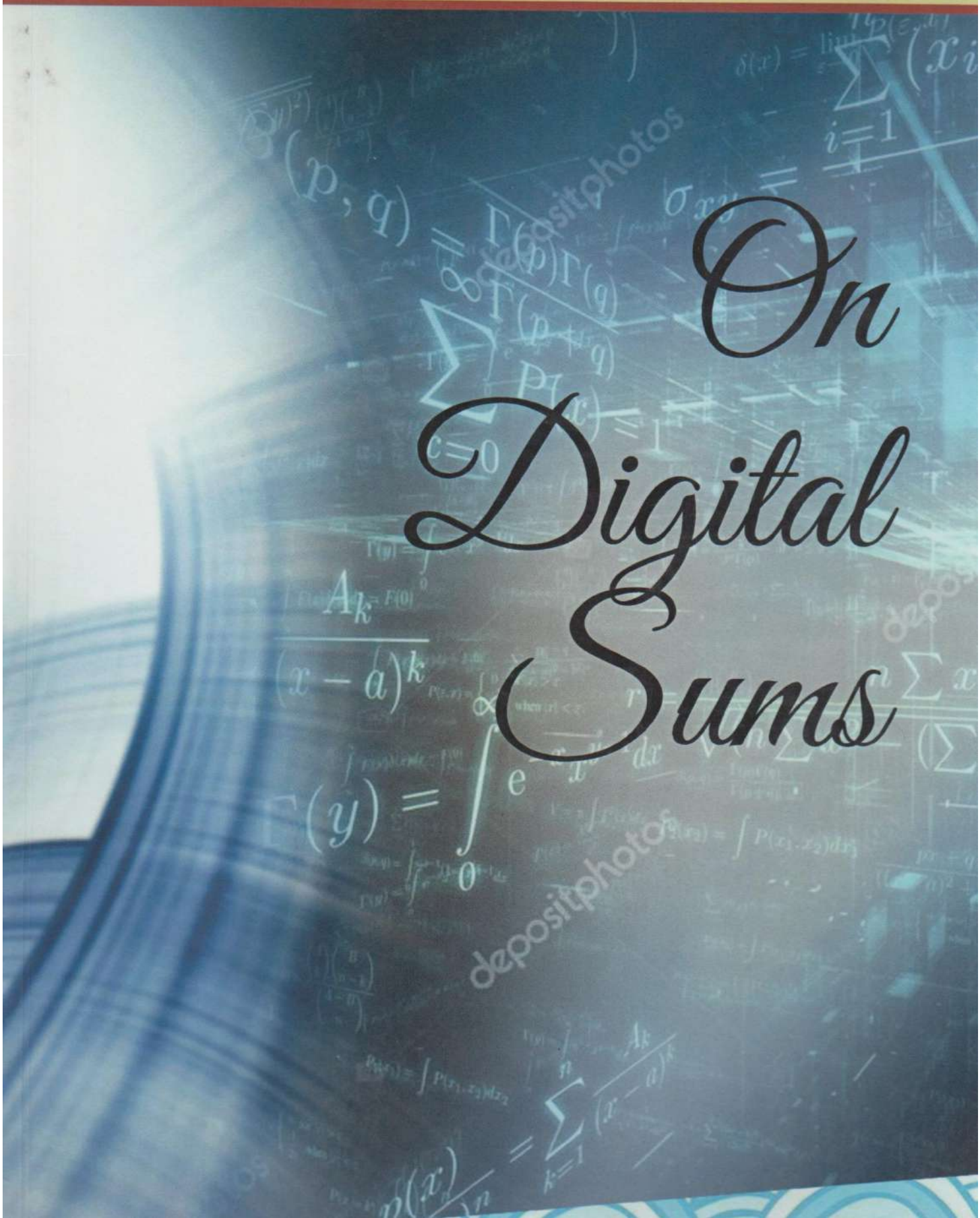
Published by: NATHI PUBLICATIONS,
1271A, Sulthanjiappa Lane, South Rampart,
Thanjavur-613 001, Tamil Nadu, India.

Private Circulation only.

All rights reserved. This book, or parts thereof, may not be reproduced in any form without the prior permission of the publisher.

ISBN: 978-93-80645-06-3

M.A.Gopalan



On Digital Sums

On Digital Sums

M.A.Gopalan, S.Vidhyalakshmi
Professors, Department of mathematics
Shrimati Indira Gandhi College
Trichy-620002, Tamilnadu, India

&

E.Premalatha
Assistant Professor
Department of mathematics
National College, Trichy-620001 Tamilnadu, India

Copyright © 2012 M.A.Gopalan

All rights reserved.

ISBN:9781520994611

This book concerns with the problem of obtaining a few sets of 2D polygonal, centered polygonal numbers, 3D pyramidal, centered pyramidal numbers, Thabit ibn Kurrah number, Kynea numbers, carol numbers, some special numbers and Arithmetic progressions (A.P) & Geometric progressions (G.P) that have nice digital sums.

It is also hoped that these problems may create interest in the hearts of researchers and lovers of mathematics who approach it with pure love for its own beauty..

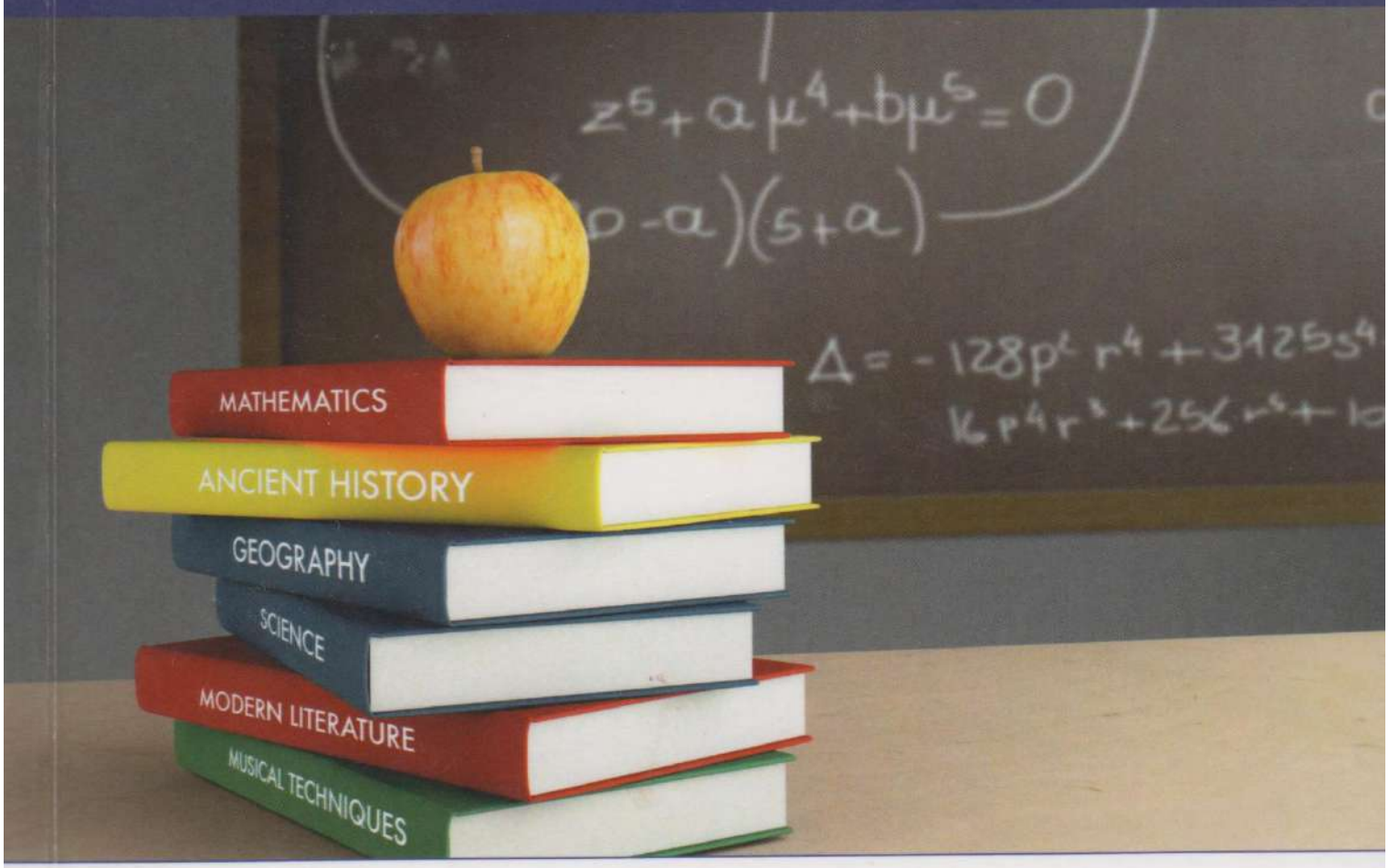


Dr.M.A.Gopalan is currently Professor of Mathematics at Shrimathi Indira Gandhi College, Tiruchirappalli and has taught Mathematics for nearly two decades. He is interested in problem solving in the area of Diophantine equations and Number Patterns. He serves as the editorial board member of IJPMS , IJAR and a life member of Kerala ?Mathematics Association.

ISBN 9781520994611

90000

9 781520 994611



M.A. Gopalan
N. Thiruniraiselvi
E. Premalatha

Special Diophantine Problems on Integer Pairs, Triples with Solutions

LAP LAMBERT Academic Publishing

M.A. Gopalan
N. Thiruniraiselvi
E. Premalatha

Special Diophantine Problems on Integer Pairs, Triples with Solutions

LAP LAMBERT Academic Publishing

Impressum / Imprint
Bibliografische Information der Deutschen Nationalbibliothek: Die Deutsche Nationalbibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliografie; detaillierte bibliografische Daten sind im Internet über http://dnb.d-nb.de abrufbar.
Alle in diesem Buch genannten Marken und Produktnamen unterliegen warenzeichen-, marken- oder patentrechtlichem Schutz bzw. sind Warenzeichen oder eingetragene Warenzeichen der jeweiligen Inhaber. Die Wiedergabe von Marken, Produktnamen, Gebrauchsnamen, Handelsnamen, Warenbezeichnungen u.s.w. in diesem Werk berechtigt auch ohne besondere Kennzeichnung nicht zu der Annahme, dass solche Namen im Sinne der Warenzeichen- und Markenschutzgesetzgebung als frei zu betrachten wären und daher von jedermann benutzt werden dürften.

Bibliographic information published by the Deutsche Nationalbibliothek: The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at http://dnb.d-nb.de.
Any brand names and product names mentioned in this book are subject to trademark, brand or patent protection and are trademarks or registered trademarks of their respective holders. The use of brand names, product names, common names, trade names, product descriptions etc. even without a particular marking in this work is in no way to be construed to mean that such names may be regarded as unrestricted in respect of trademark and brand protection legislation and could thus be used by anyone.

Coverbild / Cover image: www.ingimage.com

Verlag / Publisher:
LAP LAMBERT Academic Publishing
ist ein Imprint der / is a trademark of
OmniScriptum GmbH & Co. KG
Bahnhofstraße 28, 66111 Saarbrücken, Deutschland / Germany
Email: info@omniscriptum.com

Herstellung: siehe letzte Seite /
Printed at: see last page
ISBN: 978-3-330-05137-9

Copyright © M.A. Gopalan, N. Thiruniraiselvi, E. Premalatha
Copyright © 2017 OmniScriptum GmbH & Co. KG
Alle Rechte vorbehalten. / All rights reserved. Saarbrücken 2017

"The study of mathematics, like the Nile, begins in minuteness but ends in magnificence". The aim of this book is to give the reader an opportunity to learn and to know interesting results in the elementary theory of numbers. A reasonably large number of problems on solving systems of equations have been provided to enable the students to deepen their understanding of the subject. This book is aimed at students, researchers and anyone with an interest in numbers and equations. Some aptitude is needed for general readers. It will be particularly useful to students who wish to do research in polynomial Diophantine equations. The author's goal is to illustrate the art of finding integer solutions to systems of Diophantine equations. We hope the students may be motivated to search for integer solutions to systems of multi degree multivariate polynomial Diophantine equations.

Dr.M.A.Gopalan is currently Professor of Mathematics at Shrimati Indira Gandhi College, Tiruchirappalli and has taught Mathematics for nearly two decades.He is interested in problem solving in the area of Diophanine equations and Number Patterns.He serves on the editorial boards of IJPMS and IJAR and a life member of Kerala Mathematics Association.

978-3-330-05137-9

EMERGING TRENDS OF PHYSICAL EDUCATION AND SPORTS SCIENCE



CHIEF EDITOR
Prof. Takhellambam Inaobi Singh

EDITOR
Dr. Laishrarm Santosh Singh

CO-EDITORS:
- Dr. L. Thambal Singh
- Dr. M. Nodiyachand Singh
- Dr. M. Chourjt Singh
- Dr. Y. Santikumar Singh
- Dr. L. Pungding

ISBN: 978-93-82606-09-3

EMERGING TRENDS OF PHYSICAL EDUCATION AND SPORTS SCIENCE

Chief Editor
Prof. Takhellambam Inaobi Singh

Editor
Dr. Laishrarm Santosh Singh

Co-editors:
Dr. L. Thambal Singh
Dr. M. Nodiyachand Singh
Dr. M. Chourjit Singh
Dr. Y. Santikumar Singh
Dr. L. Pungding

INTERNATIONAL SUNMARG PUBLISHERS AND DISTRIBUTORS
H-NO 36 MAIDAN GARHI POST IGNOU NEW DEHLI -110068

ISBN: 978-93-82606-09-3

EFFECTS OF PLYOMETRIC TRAINING ON SOCCER RELATED PHYSICAL FITNESS VARIABLES OF ANNA UNIVERSITY INTERCOLLEGIATE FEMALE SOCCER PLAYERS

Dr.D.Boopathy*
Assistant Professor, Department of Physical Education, National College, Tiruchirapalli, Tamilnadu,India
Soraisham Sunilkumar Singh**
Ph.D. Research Scholar, Department of Physical Education and Sports National College, Trichirapalli-01, Tamilnadu
Dr.D.PrasannaBalaji***
Head and Director, Department of Physical Education National college, Triuchirtapalli, India.

Abstract

Plyometric training is an important training program in improving physical fitness and soccer skills of players. The study was conducted to find out the effects of plyometric training on soccer related physical fitness variables of Anna University intercollegiate female soccer players. For this study twenty female soccer players were selected through purposive sampling. The participants were engaged in a supervised plyometric training program 3 days/week for 12 weeks. The physical fitness and soccer skill variables selected for the study were: Speed, Explosive power, Agility, Dribbling, Kicking Right and Left Feet. Tests were taken three times at pre training, during training and post training. Data were analysed by using SPSS software version 20. Comparison of mean was done by paired T-test. The results obtained in this study indicated that there was significant improvement in selected physical fitness and soccer skill variables due to the effects of plyometric training. After 12 weeks of plyometric training participant's speed (MD= 0.78), agility (MD= 2.64), and explosive power (MD= 7.85) were changed significantly ($p < 0.05$). Participant's dribbling soccer skill (MD= 1.92), kicking right foot for distance (MD= 2.19) and kicking left foot for distance (MD= 2.91) were significantly improved through plyometric training. This study proved that plyometric training was significantly better in improving the physical fitness variables and soccer skills ($p < 0.05$) of female soccer players.

Key words: intercollegiate, physical fitness variables, plyometric training, soccer skills.

Introduction

Soccer (also known as football) is the world's most popular form of sport, being played in every nation without exception. Soccer has a rich history though it was formalized as we know it today by the establishment of the Football Association in 1863. The game soon spread to continental European countries and later to South America and the other continents. The world's governing body, Federation International de Football Association (FIFA), was set up in 1904 (Thomas, 2003).

Plyometric are training techniques used by players in all types of sports to increase strength and explosiveness (Chu, 1998). Plyometric consists of a rapid stretching of a muscle (eccentric action) immediately followed by a concentric or shortening action of the same muscle and connective tissue (Baechle and Earle, 2000). The stored elastic energy within the muscle is used to produce more force than can be provided by a concentric action alone 2 (Pfeiffer, 1999; Miller et al., 2002). Researchers have shown that plyometric training when used with a periodized strength-training program, can contribute to improvements in vertical jump performance, acceleration, leg strength, muscular power, increased joint awareness and overall pro-perception (Adams et al., 1992; Paasuke et al., 2001; Miller et al., 2002).

Strength, speed, and explosiveness are all crucial for success in soccer. All three of these factors are enhanced with a progressive resistance training program, but greater increases in speed and explosiveness are thought to be possible with plyometric exercise. The objective is to generate the greatest amount of force in the shortest time. A solid strength base is necessary before attempting plyometric exercises. Plyometric training is popular in sports that require powerful movements, such as basketball, soccer, volleyball, sprinting, jumping, and gymnastics. A typical plyometric exercise involves jumping off and back onto a box, attempting to rebound as quickly as possible on each jump. Box heights are increased progressively from about 12 to 22 inches. The bounding action attempts to take advantage of the stretch-recoil and stretch reflex characteristics of muscle. The rapid stretch applied to the muscle during contact with the ground is thought to augment muscle contraction, leading to more explosiveness (Hoeger, 2011).

Therefore, keeping in mind the study focused on answering the following questions:

- Is there any effect of plyometric training on soccer related physical fitness variables of Anna University intercollegiate female soccer players?
- What is the effect of plyometric training exercises on soccer skills like dribbling and kicking of Anna University intercollegiate female soccer players?

- What are the effects of plyometric training that contributes for the improvement of soccer related skills to our country's female soccer players?

Statement of the Problem

Plyometric training has many advantages for the improvement of athletes overall performance in various sport events including soccer. Plyometric training exercise improve explosive power, muscular strength, speed and quickness, agility, neuromuscular coordination, vertical jump performance, leg strength, muscular power, increase joint awareness and enhance soccer skill performances of the athletes. Haramaya University female intercollegiate soccer players were easily susceptible to many injuries in previous intercollegiate competition that plyometric training exercises can reduce it. Plyometric training is widely used in conditioning, power training and in prevention and rehabilitation of injuries in some sports (RoopchandMartin and Lue-Chin, 2010). Thus, this scientific study had provided practical information that can be used by all soccer players to develop physical fitness and soccer skill performance with simple and easy plyometric exercise training.

Materials and Methods

The study was focused on experimental study within 12 weeks of plyometric training exercises to examine soccer related physical fitness variables and soccer skills ability of the participants. For this study informal design was used. The study had only one group which consists of 20 participants in total. The training program was given to the participants for 12 weeks 3 days per week for 40 – 60 minutes per session. The pre-test was given to them to check their initial level. At the middle of the training period (six weeks) during test and after twelve weeks the post-test were taken to observe the changes.

Results and Discussion

This chapter deals with the analysis of data collected from the samples under study. The purpose of this study was to find out the effects of plyometric training on performance enhancement of selected physical fitness and soccer skills variables. To achieve the purpose of the study 20 players were purposely selected as subjects. The variables selected for this study were: speed, explosive power, agility, dribbling, kicking with right and left feet. Pre, during and post tests were conducted for all the 20 subjects on selected physical fitness and soccer skills variables and the scores were recorded. The collected data were analysed by paired 'T'test. The results for each fitness variable are discussed below.

Effects of plyometric training on physical fitness variables

Table 1. Mean values of Speed (sec), Agility (sec) and Vertical Jump (cm) for twenty Anna University intercollegiate female soccer players

Mean ± SD			
	PT	DT	PoT
SP	5.72±0.22	5.26 ± 0.20	4.94±0.15
AG	21.48±0.76	19.90±1.04	18.84±0.90
VJ	24.75±2.14	28.40±2.3	32.60±2.74

Note: values are mean ± SD, SP = Speed, AG = Agility, VJ =Vertical Jump. PT = Pre Training, DU = During Training, PoT = Post Training

Table 1 showed that, the speed, agility and explosive power of participants changed after post training. The mean difference showed that there was an improvement in speed after plyometric training. According to the above data the speed of participants was 5.72 before training and this was improved to 4.94 after progressive endurance training with a mean value difference of 0.78.

Effects of Plyometric Training on Soccer Skill Variables

Mean ± SD			
	PT	DT	PoT
DRB	19.96±1.45	19.13±1.17	18.04±0.90
KRF	20.76±3.40	21.81±3.16	22.95±3.05
KLF	15.44±3.89	16.95±3.48	18.35±3.11

Note: values are mean ± SD, DRB = Dribbling, KRF = Kicking Right Foot, KLF =Kicking Left Foot. PT = Pre Training, DU = During Training, PoT = Post Training

Table 2 showed that, soccer skills of dribbling, kicking right foot and kicking left foot were changed significantly after post training. The mean difference showed that there was an improvement in dribbling after plyometric training. Before the intervention, the mean difference value of dribbling as shown in the above table was 19.96 and improved to 18.04 after the intervention of plyometric training. This showed that the mean value difference of 26 1.92 was measured. Therefore, plyometric training significantly improved the dribbling skill of female soccer players.

The mean difference values and significant level of Anna University intercollegiate female soccer players.

Dependent Variable	Parametersl	Param-eterll	MD	Sig.
Speed (Sec)	PoT	PT DT	0.78 0.31	0.000 0.000
Agility (Sec)	PoT	PT DT	2.64 1.06	0.000 0.000
Vertical jump (cm)	PoT	PT DT	7.85 4.20	0.000 0.000
Dribbling (Sec)	PoT	PT DT	1.91 1.08	0.000 0.000
Kicking Right Foot (m)	PoT	PT DT	2.19 1.14	0.000 0.000
Kicking Left Foot (m)	PoT	PT DT	2.90 1.39	0.000 0.000

MD= mean difference, Sig= significance, PT= pre training test, DT= during training test, PoT= post training test. Sec=second, m= meter, cm= centimetre.

Table 3 showed the overall result of each test. It includes the mean difference from pre-test to post test and during test to post test and also the significance of post-tests in reference to pretest. As indicated in the above table, in all parameters remarkable and

ISBN: 978-93-82606-09-3

significant changes were observed. This was due to the plyometric training exercise they were engaged in.

Generally, the above table showed that there was visible effect of plyometric training on female participant's performance.

Conclusions

- Plyometric training program have shown significant improvement on speed performance of Haramaya University intercollegiate soccer players by reducing the time to cover the distance.
- Plyometric training greatly evoked the University female intercollegiate soccer player's kicking skill performances by increasing their kicking abilities for distance.
- The program also improved agility and explosive power of the University female soccer players
- At the end of the study period the dribbling skill of the players in relation to time showed reduction when compared to the pre training test. Therefore, it is possible to conclude that plyometric training improved the dribbling skill of intercollegiate female soccer players.
- The program has also shown significant change in improving the selected variables of physical fitness components and soccer skill variables.

REFERENCES:

1. Adams, K., P. O' Shea, L. O'Shea, M. Climstein, 1992. The effects of six weeks of squat, plyometric and squat plyometric training on power production. Journal of Applied Sports Science Research, 6: 34-41.
2. Agel, J., A. Arendt, B. Bershadsky, 2005. Anterior cruciate ligament injury in national collegiate athletic association basketball and soccer: a 13-year review. Am J Sports Med., 33: 524–530.
3. Alavi, H., 2006. Assessment and Measurement in Physical Education, Hafiz Publication, Tehran. Pp. 305.
4. Ashok, C., 2008. Test Your Physical Fitness: Kalpaz Publications; New Delhi, India. Pp. 359.
5. Astrand, P., K. Rodahl, H. Dahl, 2003. Textbook of Work Physiology, 4th ed. Champaign, IL: Human Kinetics; UK. Pp 186-195.
6. Baechle, R., W. Earle, 2000. Essentials of strength training and conditioning. 2nd edition. Taylor & Francis Group; London. Pp 274-283.
7. Bangsbo, J., M. Mohr, P. Krustrup, 2006. Physical and metabolic demands of training and match-play in the elite football player. J Sports Sci., 24: 665–674.
8. Barrow, H., R. McGee, 1979. A practical approach to measurement in physical education. Henry Kimpton; London. Pp. 280-282.
9. Bilal, M., 2003. Effect of the Plyometric Electric Training on the Development of the Explosive Power of the Legs and Its Relationship with the Performance of the Players to Some Basic Principles in Basketball. Ph.D. Thesis. Faculty of Physical Education, Alexandria University, Egypt. Pp: 70.
10. Billot, M., A. Martin, C. Paizis, C. Cometti, N. Babault, 2010. Effects of an electrostimulation training program on strength, jumping and kicking capacities in soccer players. J Strength Cond Res., 24:1407-1413.
11. Chelly, S., M. Fathloun, N. Cherif, M. Ben Amar, Z. Tabka, E. Van Praagh, 2009. Effects of a back squat training program on leg power, jump- and sprint performances in junior soccer players. J Strength Cond Res., 23: 2241–2249.
12. Chimera, J., A. Swanik, B. Swanik, J. Straub, 2004. Effects of plyometric training on muscleactivation strategies and performance in female athletes. J Athl Training., 39: 24-31.

ISBN: 978-93-82606-09-3

EVALUATING ACADEMIC PERFORMANCE OF SCHOOL CHILDRENS THROUGH PHYSICAL EDUCATION INTEGRATED MACHINE LEARNING (ML) APPROACH

[1]ANBIL MAHESH POYYAMOZHI, [2]PRASANNA BALAJI
[1,2]Department of Physical Education
National College (Autonomous)
Tiruchirappalli-01
Email: prasanna@nct.ac.in

Abstract:

In recent scenario every element of modern life, including education is rapidly being impacted by artificial intelligence (AI). Through predictions of academic sustainability or termination, AI can also offer learners extra support. Even though AI research is still in its infancy, it is important to monitor how it develops and realizes its promise over time. We can improve AI's potential for usage in sports applications and change the nature of physical education (PE), its visualization, and its repeatability. This present study analyses the principles and uses of AI in physical education and provides a targeted, in-depth research experimental design and systematic review of the areas of PE technology where AI could be used, including personalized PE programmes, knowledge provision, learner evaluation, and learner counseling techniques. Our findings shows how skilled AI techniques could be implemented to PE teachers, this study discusses how AI innovations are affecting all areas of life, including physical education. It also emphasizes the relevance of AI applications to PE technology based on existing research, which also suggests that the implications of AI for PE may apply to other educational domains.

Key Words: Physical Education, Artificial Intelligence, Children's Capability

1. INTRODUCTION

The present investigation aims to determine possibility to develop and enrich the best use of physical education programmes for strengthening and monitoring particular connected abilities together with sporting talents for the development. The study faces a number of realistic difficulties, including disputes among participants, poor communication, poor lifestyle choices made early in life, etc. These problems will be solved with the aid of painstakingly planned strategies, like machine learning and related skills, which would improve children's lives and also promote them as players and all-around effective human beings. We are all prepared to dive into the dynamic alteration of children's lives in the future, but as the studies are still in its early stages. There is evidence that supports increased physical activity and physical fitness may enhance academic achievement, and that allocating time to physical education classes, recess, and in-class physical activity may also help academic success.

The research that is currently available indicates that reading and mathematics are the academic subjects mostly influenced by physical activity. Executive function, which has been connected to physical exercise and physical health, is essential to these themes. The foundation of academic performance is executive function and brain health. Learning is facilitated by fundamental cognitive processes related to attention and memory, which are improved by exercise and greater cardiovascular fitness. Physical activity both in short bursts and over time enhances mental function and brain health. youngsters who take part in physical trainings. The network-based remote education and education system has made significant development and progress due to the rising maturity of Internet technology, computer technology, and information technology. Furthermore, teaching tasks are increasingly carried out in network environments due to the full integration of network communication technology with multimedia technology at this point, which has fundamentally altered the teaching mode. Regarding the drawbacks of conventional models, which are constrained by physical and temporal constraints, the network teaching model has the qualities of autonomy and interaction, which facilitate and improve communication between students as well as between students and professors. The network teaching model also addresses the classic single-assisted teaching paradigm's weaknesses, which include its inability to provide timely feedback on a variety of inputs.

The sports video image analysis system can collect and analyze the actual movements of the human body, improve the technical essentials of athletes, and find problems and find gaps. At present, there is no perfect sports video analysis software, which makes it difficult to correct sports movement errors. Therefore, the field of sports analysis has important application value in sports training. Motion analysis software is widely used in the daily training of sports associations around the world. The use of these systems can greatly facilitate the training of athletes. Moreover, it is an effective tool to provide in-depth analysis and comparison of the completion of technical actions after training. Sports digital training system can collect and analyze training data and simulation training results on a large scale, promote training experience to theory, and verify whether some training methods are

reasonable. With the support of computer-assisted training mode, sports training will be organically combined with information science such as statistical analysis, video processing, simulation technology, and functional technology to provide powerful tools for the development of sports training and expand the application space for information science'

The sports professional test requires that the specialty students reach a certain level in strength, speed, endurance, flexibility, and agility. This requires schools to have a complete and scientific training system for the training of high school sports students and requires physical education teachers not only to rely on the experience to train, but also to fully consider the individual differences of the students. If we hope that we can quickly improve all aspects of our specialty students in a short period of time to achieve a good level in all aspects of physical fitness, strength, sports technology, and athletic qualities, we must use different management methods and adopt different methods and methods to carry out effective sports specialty training. To improve the performance of specialty students, scientific management, scientific training and scientific selection of talents are indispensable. Then, to realize the scientific and intelligent management, training and selection is the only way. At present, information technology has become the backbone of the continuous progress of human society, and has had a huge impact on people's production and lifestyle. At the same time, the development of sports in our country is also deeply affected. Therefore, for the training of high school sports students, it is very necessary to rely on modern methods to create a convenient, fast, reasonable and practical training management system.

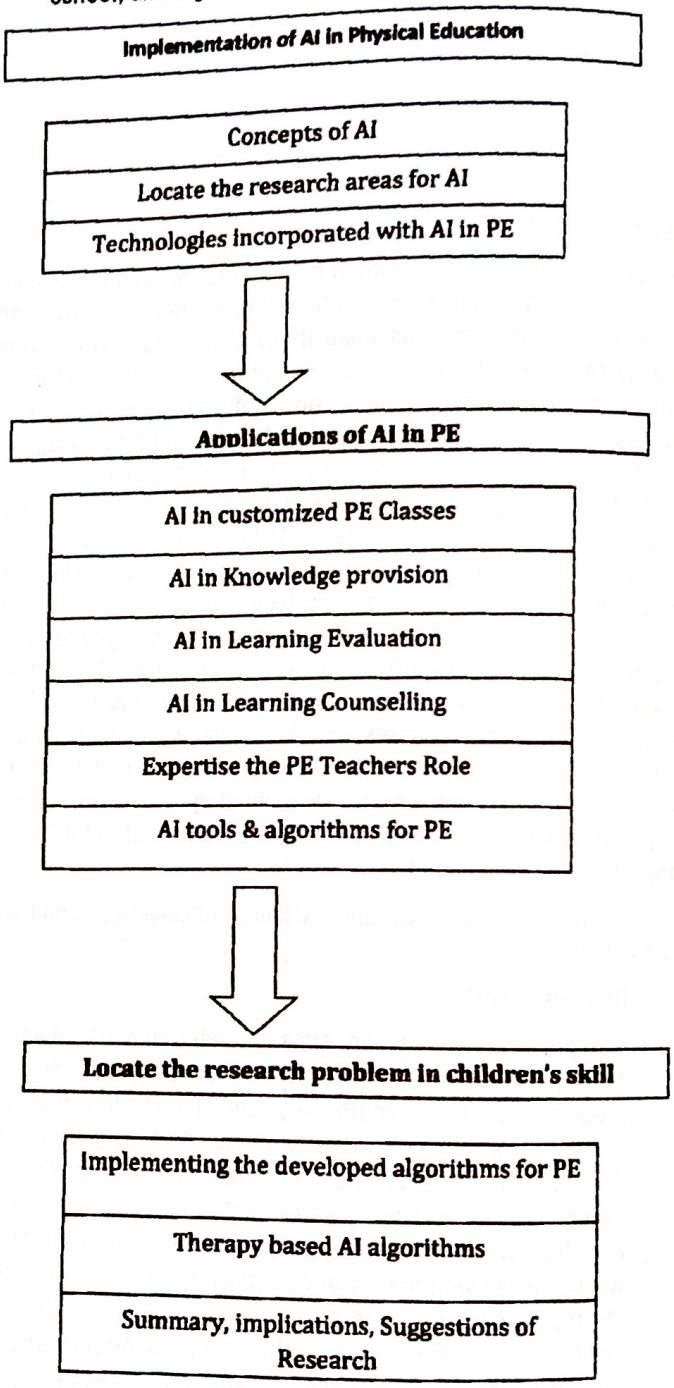
2.

3. DETAILS EXPERIMENTAL

2.1. Materials and Procedures

Methodology

As the researcher mentions that the study is at the initial stage, the researcher could explain the methodology to be undertaken for the due course. The study will commence with the observation of physical education activities in general. In the continuation of that, the infrastructure, learning and teaching resources available in the schools will be taken into consideration. A curriculum is to be designed based on a popular game in which the students of the region would love to involve and a mechanism to monitor the associated skills of Communication, Leadership, Collaborative learning, Tolerance, Interpersonal, Intra-personal, Problem Solving and Crisis Management along with sporting skill will be worked out. A government school, a private school and a government- aided school will be taken for the study simultaneously and the proposed method will be experimented in the vernacular region. Given that the study is in its early stages, the researcher should outline the approach that will be used in due time. Starting with a general observation of physical education activities, the study will proceed. The infrastructure, educational and instructional resources offered by the schools will be taken into account in the following section. A mechanism to track the associated skills of Communication, Leadership, Collaborative Learning, Tolerance, Interpersonal, Intra-personal, Problem Solving and Crisis Management along with sporting ability will be developed. The curriculum will be based on a well-liked game that the students of the area would love to participate in. The test will be administered in a government school, a private school, and a government-sponsored school.

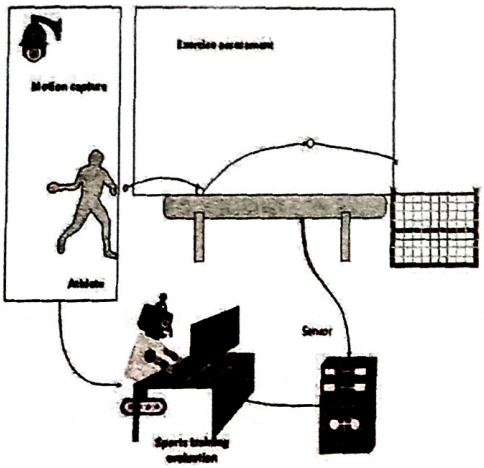


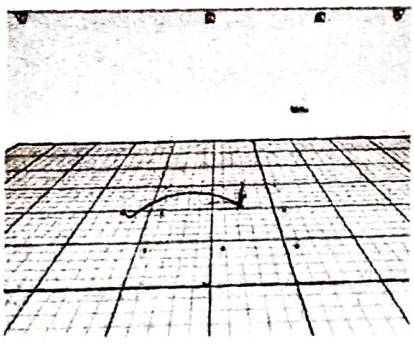
RESULTS AND DISCUSSION

3.1. As the title goes, Physical Activities for Skill Development among School Children using Machine Learning Technology, several skills would be proliferated and monitored, assessed with the aid of Physical Education. On the other hand Inter disciplinary learning could be achieved in classroom activities by incorporating

 ISBN: 978-93-82606-09-3

the virtues attained from physical activities. This study would enable the potential to unearth the importance of inculcating regular physical education activities much more productive and vibrant by nurturing entire related skills mentioned in the study. It would encompass the teachers of other subjects to offer integrated instructions through physical activities. Predominantly this research focuses on to deduce the boredom and maximise learning through activity based teaching and learning process. The sports digital training system is of great significance to the development of sports. The sports video image analysis system can collect and analyze the actual movements of the human body, improve the technical essentials of athletes, and find problems and find gaps. At present, there is no perfect sports video analysis software, which makes it difficult to correct the movement error. Therefore, it has important application value in the field of sports analysis in sports training. This study uses the Internet of Things technology to achieve long-term uninterrupted data collection. After certain processing of the data, an extreme learning machine is used to predict the situation of sports training. In order to solve some shortcomings of the original extreme learning machine, gradual optimization is carried out from two aspects of hidden layer mapping and parameter optimization to further improve the accuracy of prediction. Moreover, this research constructs a physical education training system based on actual needs to optimize the physical education and training process. In addition, this paper designs experiments to verify the performance of the system constructed in this paper. From the experimental research, it can be seen that the system constructed in this paper can basically meet the actual needs of physical education and training.





CONCLUSIONS

This study positively elevates the dynamic ideologies of profound transformation in the learning curriculum of children.

Previous research and academic evidences suggests that increasing physical activity and physical fitness may improve academic performance and that time in the school day dedicated to recess, physical education class, and physical activity in the classroom may also facilitate academic performance.

Available evidence suggests that mathematics and reading are the academic topics that are most influenced by physical activity. These topics depend on efficient and effective executive function, which has been linked to physical activity and physical fitness.

Executive function and brain health underlie academic performance. Basic cognitive functions related to attention and memory facilitate learning, and these functions are enhanced by physical activity and higher aerobic fitness.

Single sessions of and long-term participation in physical activity improve cognitive performance and brain health. Children who participate in vigorous- or moderate-intensity physical activity benefit the most.

Given the importance of time on task to learning, students should be provided with frequent physical activity breaks that are developmentally appropriate.

Although presently understudied, physically active lessons offered in the classroom may increase time on task and attention to task in the classroom setting.

6. ACKNOWLEDGMENTS

I would like to express my special thanks of gratitude to **K Raghunathan, Secretary, National College (Autonomous), Tiruchirappalli** as well as our principal who gave me the golden opportunity to do this wonderful project on the topic Importance of Physical Fitness to Elevate the Academic Skills in School Children's, which also helped me in doing a lot of Research.

7. REFERENCES

1. Rein R, Memmert D (2016) Big data and tactical analysis in elite soccer: future challenges and opportunities for sports science[J]. Springerplus 5(1):1–13
2. Ridderinkhof KR, Brass M (2015) How kinesthetic motor imagery works: a predictive-processing theory of visualization in sports and motor expertise[J]. J Physiol-Paris 109(1–3):53–63
3. Mulligan D, Lohse KR, Hodges NJ (2016) An action-incongruent secondary task modulates prediction accuracy in experienced performers: evidence for motor simulation[J]. Psychol Res 80(4):496–509
4. Khudolii OM, Ivashchenko OV, Iermakov SS et al (2016) Computer simulation of junior gymnasts' training process[J]. Sci Gymnast J 8(3):215–228

5. Tivener KA, Gloe DS (2015) The effect of high-fidelity cardiopulmonary resuscitation (CPR) simulation on athletic training student knowledge, confidence, emotions, and experiences[J]. Athl Train Educ J 10(2):103–112

6. Ivashchenko OV, Kapkan OO (2015) Simulation of process of 14–15 years old girls' training of light athletic and gymnastic exercises[J]. Pedag, Psychol, Med-Biol Probl Phys Train Sports 8:32–40

7. Owen PD, King N (2015) Competitive balance measures in sports leagues: the effects of variation in season length[J]. Econ Inq 53(1):731–744

8. Yang J (2019) The Simulation of table tennis during the course of sports[J]. Carib J Sci 52(4):1561–1564

9. Bulat M, Can NK, Arslan YZ et al (2019) Musculoskeletal simulation tools for understanding mechanisms of lower-limb sports injuries[J]. Curr Sports Med Rep 18(6):210–216

10. Payne T, Mitchell S, Bibb R et al (2015) The evaluation of new multi-material human soft tissue simulants for sports impact surrogates[J]. J Mech Behav Biomed Mater 41(5):336–356

11. Juan Pablo ngel-Lo´pez, Nelson Arzola de la Pen´a. (2015) Kinematic hand analysis using motion capture technology[J]. IFMBE proceedings, 49(6):257-260.

12. Kim MK, Kim TY, Lyou J (2015) Performance improvement of an AHRS for motion capture[J]. J Institute Control 21(12):1167–1172

ISBN: 978-93-82606-09-3

IMPACT OF THERABAND TRAINING, PILATES TRAINING AND PLYOMETRICS TRAINING ON SELECTED PHYSICAL FITNESS VARIABLES AMONG STATE LEVEL MEN ARTISTIC GYMNASTS

P S Poukinreiyang Kamei*
Ph.D. Research Scholar, Department of Physical Education and Sports
National College, Trichirapalli-01, Tamilnadu
Dr.D.Boopathy**
Assistant Professor, Department of Physical Education,
National College, Tiruchirapalli, Tamilnadu,India
Dr. D. Gunaseelan***
Assistant Professor & Research Advisor,
Department of Hotel Management,
Jamal Mohamed College (Autonomous) Trichy

Abstract:

Sports play a very prominent role in the modern society. It is important to individuals, a group, a nation and indeed the world. Throughout the world, sports have popular appeal among people of all ages and both sexes. Much of the attraction of sports comes from the wide variety of experience and feeling that result from participation such as success, failure, exhaustion pain, relief and feeling of belonging. Sport can bring money, glory, status and goodwill. However, sport can also bring tragedy, grief and even death (Coakley, jay J.,1998)

The objective of this research was to assess the selected motor fitness variables of state level men artistic gymnastics (speed, abdominal strength, flexibility) the adjusted mean on speed on plyometrics training group was 7.08, pilates training group was 7.11, theraband training group was 7.13 and control group was 7.32, the adjusted mean on abdominal strength on pilates training group was 38.26, plyometric training group was 38.22, thera band training group was 40.09 and control group was 36.43, the adjusted mean on Flexibility on thera band group was 24.07, plyometrics training group was 23.82, pilates training group was 24.05 and control group was 21.51.

Key Words: Gymnastics, Speed, Abdominal Strength, Flexibility, thera band training, plyometrics training, pilates training.

Introduction:

Artistic gymnastic is one of the few sports which can be practiced from a very young age, and which develops different components of physical fitness. Pupils learn basic elements which are of great significance, especially for children's orientation in space, such as jump and leaps, hanging, rotating, crawling, rolling, etc. (Pajek, Cuk, Kovac, & Jakese, 2010). Motor fitness (speed, agility and coordination), and cardirespiratory fitness (ALPHA, 2009; Artero et al.,2011; Ruize et al., 2010). There are different fitness test batteries, such as Alpha-fit, Eurofit, Fitnessgram, Etc., which are applied around the world in order to assess physical fitness in children and adolescents (Kolimechkov, 2017).

Sports plays a important role in the modern society. It is important to individuals, a group, a nation and indeed the world. Throughout the world, sports have a popular appeal among people of all ages and both sexes. Much of the attraction of sport comes from the wide verity of experience and feeling that result from participation as success, failure, exhaustion pain, relief and feeling of belonging. Sports can bring money, glory, status and goodwill. However, sport can also bring tragedy, grief and even death (Coakley, Jay J., 1998).

Preparation of an athlete today for achievement is a complex dynamic matter, characterized b a high level of physical and physiological efficiency and the degree of perfection of necessary skills, knowledge proper teaching and tactics. An athlete arrives at this state only, as a result of corresponding training sports activity directed at steadily enhancing the preparation of an athlete and grooming him for a higher-level achievement. Fitness is a state which often characterizes the degree to which a person is able to function. Ability to function depends upon the physical, mental, emotional, Social and spiritual components of fitness. While fitness is the maximal, economical and efficient functioning of the body, health is referred to as optimal homeostatic functioning of the body.

Objectives of the study:

The objective of the research was to assess the selected physical fitness variables of 12 to 14 years state level gymnasts, to find out the effect of varied training methods, such as Thera band trainng, Plyometric Trainng and pilates training on selected physical variables. The effect of Thera band trainng, Plyometric Trainng and pilates trainingon gymnasts on each of the physical fitness variables was compared with these effects with control group to determine whether these training produce significant changes in the selected variables. If so, which of the training method is better than the other one? Thus, the current research focuses on the effects of varied training packages such as Thera band trainng, Plyometric Trainng and pilates training on selected physical fitness variables.

Methodology:

Physical Fitness Variables:
1. Speed 2. Abdominal Strength 3. Flexiblity
Independent Variables
1. Twelve-week Thera band Training
2. Twelve weeks Plyometrics Training
3. Twelve weeks Pilates Training

Selection of subjects:

To achieve the purpose of this study sixty state level men artistic gymnasts from different clubs in trichy were selected. The selected subject's age group was ranging from twelve to fourteen years. group one acted as experimental group one and group two acted as experimental group two and group three acted as experimental group three and group four acted as control group. Group- four underwent routine activities and care was taken that they should not involve in special exercise programmes. Before starting the study, all subjects were informed about it and signed an informed consent form.

Warm up and cool down exercise:

All subjects started every training session with 5 minutes of walking and jogging. After that, they performed gymnastics stretching exercise including upper and lower body extremities for 10 minutes. Subjects performed 5 minutes jogging for a cool down at the end of each training session.

Flexibility test:

Sit and reach test were used to obtain subjects flexibility scores. Subjects performed two trails within 1-minute rest period between the trails for flexibility test. The best score was recorded. The subject was asked to wait at least 2 seconds at the maximum reached distance. The trail was not considered successful if the subject a) failed to maintain the contact with the target, b) failed to maintain position at least 2 seconds at maximum reached distance.

Speed Test: 30mts Dash

The test involves running a single maximum sprint over 30 meters, with the time recorded. A through warm up should be given, including some practice starts and accelerations. Start form a stationary position, with one foot in front of the other. The front foot must be on or behind the starting line. This starting position should be held for 2seconds prior to starting, and no rocking movements are allowed. Two trails are allowed and the best time is recorded to the nearest 2 decimal places. The timing starts from the first movement (if using a stopwatch) or when the timing system is triggered, and finishes when the chest crosses the finish line the finishing trimming gate is triggered.

Plank Test: Abdominal Strength:

The aim of this test is to hold an elevated position for as long as possible. Start with upper body supported off the ground by the elbows and forearms, and the legs straight with the weight taken by the toes. The hip is lifted off the floor creating a straight line from head to toe. As soon as the subject is in the correct position, the stopwatch is started. The head should be facing towards the ground and not looking forwards. The test is over when the subject is unable to hold the back straight and the hip is lowered. The score is the total time completed.

Significance of the study:

The study is significant in the following ways:

1. This study is unique in suggesting varied training schedules for the physical fitness variables of state level men artistic gymnasts.

2. The findings of this study would suggest which training schedule is better in improving and developing which of the specific physical fitness variables of men gymnasts.

3. The findings would be helpful for the coaches and administrators to modify their existing training schedules for the preparation of gymnast's probable.

4. This study may help the sports scientists to suggest ways and means to improve better standard in sports through suggesting suitable training methods.

5. This study may help the coaches and physical educators to train the gymnasts to improve

Analysis of Data

Computation of analysis of covariance due to thera band training.plyometric training and pilates training and control group on speed

	Source of variance	Sum of squares	Df	Mean Squares	Obtained F
Pretest Mean	Between	0.17	3	0.06	0.47*
	Within	9.30	76	0.12	
Post-test mean	Between	1.16	3	0.39	4.55*
	Within	6.44	76	0.08	
Adjusted Post -test Mean	Between	6.71	3	0.24	22.76
	Within	6.79	75	0.01	

Required F(0.05), (df3,75) = 2.77

**Significant at 0.05 level of confidence*

As shown in Table 4.2, the obtained F- Raito of 0.47 on pre0test means of the groups was not significant at 0.05 level as the obtained F- value was less than the required table F-Value of 2.77 to be significant at 0.05 level. This shows that there was no significant difference in means of the groups at initial stage. The results presented in table 4.2, the obtained F-ratio of 4.55 on post- test means of the group was significant at 0.05 levels as the obtained F-value was grater then the required table F-value of 2.77 to be significant at 0.05 levels. This shows that there was a significant difference in means of the groups at initial stage. Taking into consideration of the pre-test mans and post-test means, adjusted post0test means were determined and analysis of covariance was done. The obtained F-value on adjusted means was 22.76. The obtained F-value was greater than the required value of 2.77 and,

ISBN: 978-93-82606-09-3

hence it was accepted that there were significant differences among adjusted means on the speed of the subjects.

Computation of analysis of covariance due to thera band training.plyometric training and pilates training and control group on abdomianl strength

	Source of variance	Sum of squares	Df	Mean Squares	Obtained F
Pre-test Mean	Between	115.04	3	38.35	0.96
	Within	3025.85	76	39.81	
Post-test mean	Between	137.70	3	45.90	1.58
	Within	2213.30	76	29.12	
Adjusted Post -test Mean	Between	132.71	3	44.24	84.97*
	Within	39.05	75	0.52	

Required F(0.05), (df3,75) = 2.77

**Significant at 0.05 level of confidence*

As shown in Table 4.5, the obtained F- Raito of 0.96 on pre-test means of the groups was not significant at 0.05 level as the obtained F- value was less than the required table F-Value of 2.77 to be significant at 0.05 level. This shows that there was no significant difference in means of the groups at initial stage. The results presented in table 4.5, the obtained F-ratio of 1.58 on post- test means of the group was significant at 0.05 levels as the obtained F-value was grater then the required table F-value of 2.77 to be significant at 0.05 levels. This shows that there was a significant difference in means of the groups at initial stage. Taking into consideration of the pre-test mans and post-test means, adjusted post0test means were determined and analysis of covariance was done. The obtained F-value on adjusted means was 84.97. The obtained F-value was greater than the required value of 2.77 and, hence it was accepted that there were significant differences among adjusted means on the speed of the subjects.

Computation of analysis of covariance due to thera band training. plyometric training and pilates training and control group on flexiblity

	Source of variance	Sum of squares	Df	Mean Squares	Obtained F
Pre-test Mean	Between	3.74	3	1.25	0.22
	Within	438.65	76	5.77	
Post-test mean	Between	79.64	3	26.55	5.38*
	Within	374.85	76	4.93	
Adjusted Post -test Mean	Between	92.27	3	30.76	18.81*
	Within	122.66	75	1.64	

*Required F(0.05), (df3,75) = 2.77 *Significant at 0.05 level of confidence*

As shown in Table 4.8, the obtained F- Raito of 0.22 on pre-test means of the groups was not significant at 0.05 level as the obtained F- value was less than the required table F-Value of 2.77 to be significant at 0.05 level. This shows that there was no significant difference in means of the groups at initial stage. The results presented in table 4.5, the obtained F-ratio of 5.38 on post- test means of the group was significant at 0.05 levels as the obtained F-value was grater then the required table F-value of 2.77 to be significant at 0.05 levels. This shows that there was a significant difference in means of the groups at initial stage. Taking into consideration of the pre-test mans and post-test means, adjusted post0test means were determined and analysis of covariance was done. The obtained F-value on adjusted means was 18.81. The obtained F-value was greater than the required value of 2.77 and, hence it was accepted that there were significant differences among adjusted means on the speed of the subjects.

Results & Conclussions

1. It was concluded that varied packages of training, namely plyometric training, thera band training and pilates training significantly improved physical fitness variable, such as speed among state level gymnasts compared to control group. It was also found that there was no significant difference among treatment groups in altering speed.

2. 1. It was concluded that varied packages of training, namely plyometric training, thera band training and pilates training significantly improved physical fitness variable, such as abdominal strength among state level gymnasts compared to control group. It was also found that there was no significant difference among treatment groups in altering abdominal strength.

3. It was concluded that varied packages of training, namely plyometric training, thera band training and pilates training significantly improved physical fitness variable, such as flexibility among state level gymnasts compared to control group. It was also found that there was no significant difference among treatment groups in altering flexibility.

REFERENCES:

5 *1.Borresen, J., & Ian Lambert, M. (2009). The Quantification of TrainingLoad, the Training Response and theEffect on Performance. Sports Medicine,39(9), 779–795.*

6 *2.Harriss, D. J., MacSween, A., &Atkinson, G. (2019). Ethical Standards in Sport and Exercise Science Research: 2020 Update. International Journal of Sports Medicine, 40(13), 813–817.*

7 *3.Foster, C., Florhaug, J. A., Franklin, J., Gottschall, L., Hrovatin, L. A., Parker,S., ... Dodge, C. (2001). A New Approachto Monitoring Exercise Training. Journalof Strength and Conditioning Research,15(1), 109–115.*

8 *4.Alcaraz, P.E., Palao, J.M &Elvira, J.L. (2009). Determining the optimal load for resisted sprint training with sled showing. J Strength Cond Res. 23(2):480-5.*

9 *5.Hoeger, W. W., & Hoeger, S. A. (2013). Principles and labs for physical fitness: Cengage Learning.*

10 *6.Hosmer, D., Lemeshow, S., & Sturdivant, R. (2000). Applied Logistic Regression. New York, NY: A WileyInterscience Publication. In: John Wiley & Sons Inc.*

11 *7.Creswell, J. W. (2012). Educational research: planning, conducting, and evaluating quantitative and qualitative research. Boston: Pearson.*

12 *8.Hoeger, W. W., & Hoeger, S. A. (2013). Principles and labs for physical fitness: Cengage Learning.Hosmer, D., Lemeshow, S., & Sturdivant, R. (2000). Applied Logistic Regression. New York, NY: A WileyInterscience Publication. In: John Wiley & Sons Inc.*

 ISBN: 978-93-82606-09-3

THE IMPORTANCE OF HEALTH, FITNESS AND WELLNESS

Dr.Rn Woreithing
Assistant Professor, Department of Physical Education,
National College, Tiruchirapalli, Tamilnadu,India
P S Poukinreiyang Kamei,
Ph.D. Research Scholar, Department of Physical Education and Sports
National College, Trichirapalli-01, Tamilnadu
Soraisham Sunilkumar Singh
Ph.D. Research Scholar, Department of Physical Education and Sports
National College, Trichirapalli-01, Tamilnadu

Abstract

In the present of world of space age and automation era, all human being appear to be living in a more and more inactive life, they ride instead of walk, sit instead of stand and watch instead of participating. Such type of inactivity or sedentary life is detrimental to mental and physical health, Thus there is a great need for physical education as a part of balanced living.

Physical activity ought to become as a routine of every living human being for achieve their goal of life. The sports such as cycling, swimming, jogging, walking, aerobics, and soccer played regularly, are not only for fun but could promote healthy life. Physical activity can be healthful in the every way which you could do with the proper ways and through guidance. Physical activities also reduce the level of fatigue, distress anxiety and other type of uncomforted and maintain proper health, weight which is very useful to keep strong from the diseases and give us a peacefulmind to live a tremendous life through a physical activities.

Primary components of fitness

Cardio respiratory capacity

Muscular Capacity
Flexibility
Body Composition

Secondary Components of Fitness

Balance
Coordination
Agility
Reaction time
Speed
Power
Mental Capability
Health and wellness
Social health
Mental health
Emotional health
Spiritual health

The Importance of Health, Fitness and wellness

In the present of world of space age and automation era, all human being appear to be living in a more and more inactive life, they ride instead of walk, sit instead of stand and watch instead of participating. Such type of inactivity or sedentary life is detrimental to mental and physical health, Thus there is a great need for physical education as a part of balanced living.

Primary components of fitness

The four primary components (also known as the components of health related fitness) that are important to improved physical health are as follows.

Cardio respiratory capacityis the ability of the body to take in oxygen (respiration), and used it at the cellular level to create energy (Bioenergetics) for physical work (activity). In fitness, we also refer to cardio respiratory capacity as aerobic capacity. This capacity includes aerobic endurance (how long) aerobicpower (how fast). Some of the long term adaptations of cardio respiratory training are: decreased resting heart rate, decreased risk of cardio vascular disease, improve endurance, increase stroke volume and cardiac output.

Muscular Capacity refers to the spectrum of muscular capability, this includes muscular endurance (i.e. the ability to apply force over a long period of time or to compete repeated muscle contraction); Muscular strength (i.e. the ability to generate force, or the maximum amount of force that a muscle can exert in a single contraction); and muscular power) i.e., the ability to generate strength In an explosive way) some of the long term adaptations of improving muscular capacity are increased strength, improved muscular endurance, increased basal metabolic rate, improved joint strength and overall posture.

Flexibilityis the range of movement or amount of motion that a joint 1 capable of performing, each joint has a different amount of flexibility, some of the long term adaptations of improved flexibility are decreased risk o injury, improved range of motion, improved bodily movements and improved posture.

Body composition

Is the proportion of fat- free mass (muscle, bone, blood, organs and fluids) to fat mass(adipose tissues deposited under the skin and

around organs) Some of the long term adaptations of improving body composition are decreased risk of cardiovascular diseases improved basal metabolic rate, improved bodily function and improved **BMI**

Secondary Components of fitness

The secondary components of fitness (also known as the components of performance based fitness) are involved in all physical activity and are necessary for the daily functioning athletes experience different levels of success depending on how well these secondary fitness components are developed. Although the primary components of fitness are thought to be the most important, we should not ignore the secondary components because of their importance in the completion of daily tasks. The secondary components include the following.

Balance is the ability to maintain a specific body position in either a stationery or dynamic (moving) situation.

Coordination is the ability to use all body parts together to produce smooth and fluid motion.

Agility is the ability to change direction quickly

Reaction time is the time required to respond to a specific stimulus.

Speed is the ability is to move rapidly, speed is also known as explosive strength.

Power is the product of strength and speed, power is also known explosive strength.

Mental capability is the ability to concentrate during exercise to improve training effects as well as the ability to relax and enjoy the psychological benefits of activity (endorphins).

Health and wellness

Health is a dynamic process because it is always changing. We all have times of good health, times of sickness, and may be even times of serious illness as our lifestyle change so does our level of health.

Those of us who, participate in regular physical activity do so partly to improve the current and future level of our health. We strive toward on optimal state of well-being. As our lifestyle improves and we experience less disease and sickness, when most people are asked what it means to be healthy, they normally respond with the four components of fitness mentioned earlier.(cardio respiratory ability, muscular ability, flexibility and body composition).Although these components are a critical part of being healthy, they are not the only contributing factors. Physical health is only one aspect of our overall health.

The other components of health (Greenberg,2004, p.7) that are just as important as physical health include the following.

Social health – The ability to interact well with people and the environment and to have satisfying personal relationships.

Mental health – The ability to learn and grow intellectually. Life experience as well as more formal structures enhances mental health.

Emotional health- The ability to control emotions so that you feel comfortable expressing them and can express them appropriately.

Spiritual health- A belief in some unifying force. It varies from person to person but has the concept of faith at its core. Wellness is the search for enhanced quality of life, personal growth and potential through positive lifestyle behaviors and attitudes. If we take responsibility for your own state of wellness including nutrition physical activity, stress- coping methods, good relationship and career success.

Each day we work toward maximizing our level of health and wellness to live long full and healthy lives. The pursuits of health, personal growth and improve quality of life relies on living a balanced life to achieve balance; we need to care for our mind body and spirit.

If any one of these areas is consistently lacking or forgotten about, we will not be at our optimal level of health, we are constantly challenged with balancing each of these three areas throughout life.

As fitness professional we have responsibilities to guide and motivate others to improve their level of health and wellness. We can promote a holistic approach to health (mind, body and spirit) not just encourage physical activity. As good role models, we should demonstrate positive health behaviours that assist in improving our own health and the health of others. If our focus is strictly on the physical benefits of exercise we are doing a disservice two hour clients and we are not fulfilling our professional obligation.

Benefit of physical activity

As fitness professional we spend a greater deal of time inspiring and assisting others in their pursuit of improving health. Education is important aspects of these we must promote be benefits of regular activity and help people understand why they should be active.

Activity guideline

Health Canada introduced Canada's physical activity guide to healthy active living to help Canadians make wise choice about physical activity as a way to improve health. Scientist say you should accumulate 60 minutes wise choice about physical activity everyday to stay healthy or improve health. The recommendations in the physical activity guide are as follows.

- Endurance on 4 to 7 days a week, perform continuous activity for your heart, lungs and circulatory system. Time required for improvements depends on effort.
- Flexibility on 4 to 7 days a week, perform gentle reaching, bending and stretching to keep muscles relaxed and joints mobile.
- Strength on 2 to 4 performs resistance exercise to strengthen muscles and bones and improve posture. The American college of sports medicine (ACSM) has also developed activity guidelines for improving health.
- Perform 30 minutes or more for moderate intensity physical activity on most days of the week for cardiovascular health, the 30 minutes need and endurance.

ISBN: 978-93-82606-09-3

- Performing 1 set of 8 to 12 repetitions of resistance training for the entire body is necessary to maintain and develop muscular strength and endurance.
- Flexibility training should be performed daily. Including stretches for all major muscles groups in order to maintain mobility.

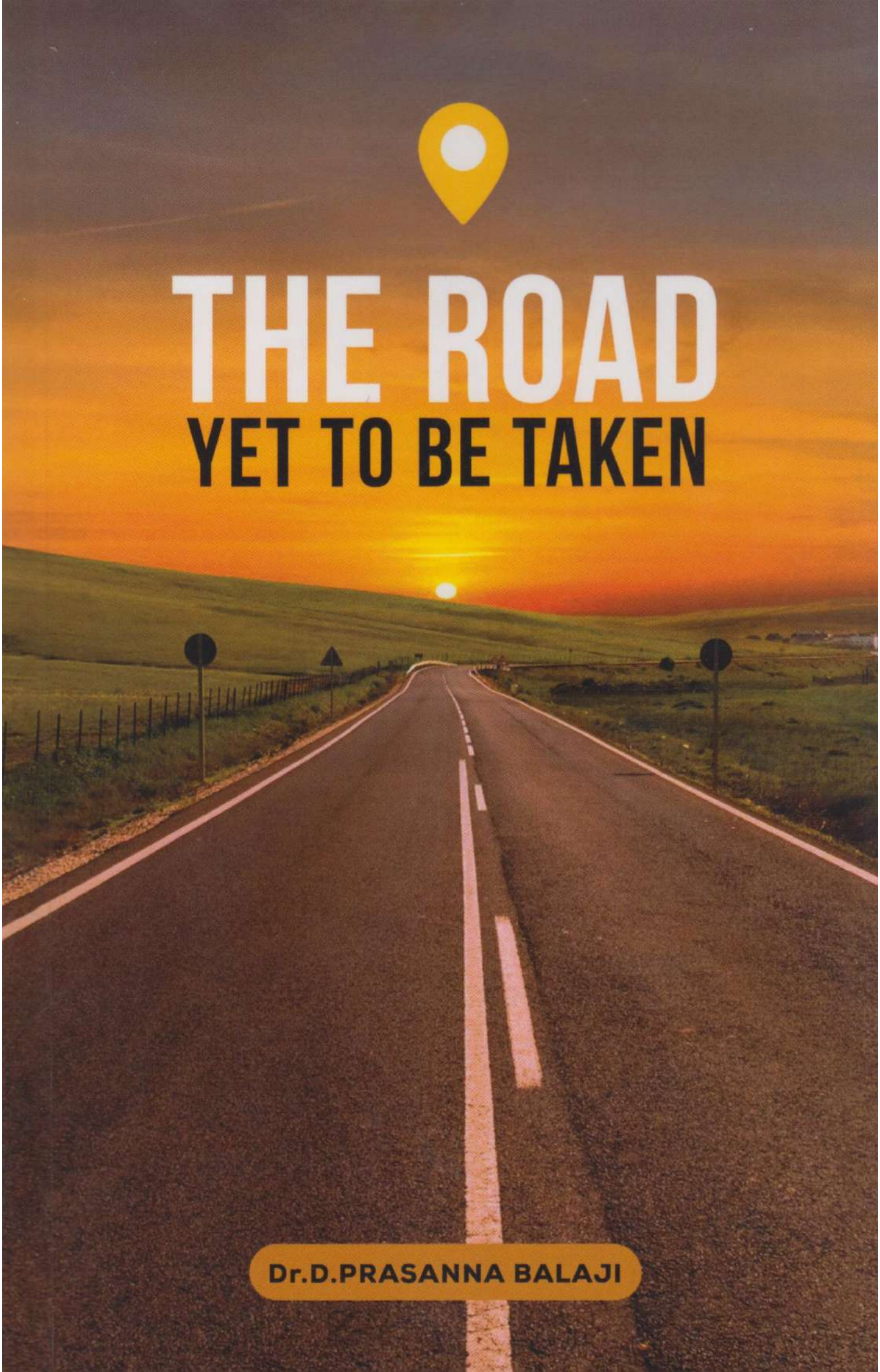
Benefits	Effects on health
Reduce the risk of pre mature death	Active people live longer with a better quality of life
Reduce the risk of cardio vascular disease	Strengthens the heart, cardio vascular system and respiratory help fight cardio vascular disease
Decrease resting heart rate	Reduce the daily wear and tear on the cardio vascular system
Keeps resting blood pressure normal	Improve the ability to for form daily activities at higher integral greater ease
Improves heart efficiency	Reduce the risk of mature life-threatening diseases, such as cardio vascular diseases and diabetes.
Decrease body far	Develops strong abdominals and back muscles easier and safer when the body has better control
Promotes joints stability	All movements in daily life become easier and safer when the body has better control
Increases muscular strength	An improved outlook on life makes all activities more enjoyable
Strengthen bones	Everyday life becomes more enjoyable because the person has a positive way to deal with stress

Conclusion:

Physical fitness is one of the most important elements of leading a healthy life style. Physical education promotes the importance of inclusion of a regular fitness activity in the routine. This helps the students to maintain their fitness, develops their muscular strength, increase their stamina and thus stretch their physical abilities and optimal level.

REFERENCE:

1. **Bauman A. E. (2004).** Updating the evidence that physical activity is good for health: an epidemiological review 2000-2004. J sci med sports;7(1supp1): pp. 6-19.
2. **Penedo F.J., Dahn J.R. (2005).** Exercise and wellbeing: a review of mental and physical health benefits associated with physical activity. Curropin psychiatry; 18(2): pp. 189-93.
3. **Littman A.J., Forsberg C.W., Koepsell T.D. (2009).** Physical activity in national sampleof veterans. Med sci. sports exerc; 41(5): pp. 1006-13.
4. http;//bodyfitnesshealth.com/benefits-and-importance-of-physical-education
   www.humankinetics.com/exeperts/exeperts/the-importance-of-health-fitness-and wellness.


THE ROAD
YET TO BE TAKEN
Dr.D.PRASANNA BALAJI

THE ROAD YET TO BE TAKEN

by : Dr. D.Prasanna Balaji

© Publisher

All rights reserved, no part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means, electronic, mechanical, photocopying, recording or otherwise without the prior written permission of the publisher or the copyright holder.

ISBN : 978-93-92274-91-6

Published in 2023 by

NATIONAL ACADEMIC PRESS

#25/57, Mohammed Hussain Street,
Royapettah, Chennai- 600 014
Email : nationalacademicpress@gmail.com

Printed and bound in India

TABLE OF CONTENTS

Foreword 4

Preface 6

Appreciation 9

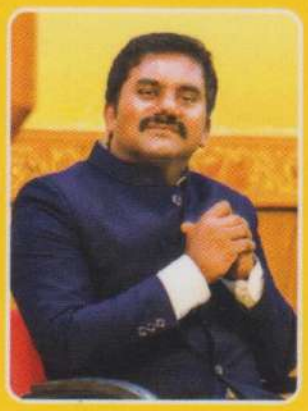
Proper Prior Planning
Prevents Poor Performance 12

Procrastination is The Enemy of Productivity 43

Crisis Management 68

Science of Health 75

Traditional Food 101



"We live, work, and play in a competitive setting. To be successful on the sports field or in the workplace, we must win. As a result, we are fighting for the success-oriented commitment of our Management and team members. Healthy competition is energising, inspiring, and does not hinder the performance of the team."

-From the Chapter: Science of Health

Dr. D. Prasanna Balaji, apart from being the author of this book, he is a highly accomplished professional in the field of physical education and sports sciences. He is an Ambassador for the International Organisation of Health, Sports, and Kinesiology (IOHSK), USA. He has earned a Ph.D. in physical education and is a member of several prestigious professional organizations. As the Vice Principal, Director, and Head of the PG & Research Department of Physical Education and Sports Sciences at National College (Autonomous) in Tiruchirappalli, Tamil Nadu, India, Dr. Balaji has made significant contributions to the field. He has received numerous awards and accolades, including the Outstanding Award for Professional Excellence by the International Federation of Physical Education, Fitness, and Sports Science (IFPEFSS), and is a respected figure in promoting fitness and well-being.

NATIONAL
ACADEMIC PRESS

ISBN 978-93-92274-91-6
9 789392 274916

Research Methodology and Publication Ethics

-A Researchers' Handbook



Dr. K. Ravichandran
Dr. A.T. Ravichandran
Dr. M. Ayyanar
Dr. P. Kavitha

Research Methodology and Publication Ethics

- A Researchers' Handbook

Dr. K. Ravichandran
Associate Professor and Head
PG & Research Department of Physics
AVVM Sri Pushpam College (Autonomous)
Poondi, Thanjavur - 613 503
Tamilnadu, India

Dr. A.T. Ravichandran
Associate Professor
PG & Research Department of Physics
National College (Autonomous)
Tiruchirappalli - 620 017
Tamilnadu, India

Dr. M. Ayyanar
Assistant Professor
PG & Research Department of Botany
AVVM Sri Pushpam College (Autonomous)
Poondi, Thanjavur - 613 503
Tamilnadu, India

Dr. P. Kavitha
Assistant Professor
PG & Research Department of Zoology
AVVM Sri Pushpam College (Autonomous)
Poondi, Thanjavur - 613 503
Tamilnadu, India

Published by

JAZYM PUBLICATIONS

Trichy-620 023, India.

Phone: 94435 87233

©2022 JAZYM Publications.

Printing of books passes through many stages – writing, composing, proof reading, printing etc. We try our level best to make the book error free. If any mistakes has inadvertently crept in, we regret it and would be deeply indebted to those who point it out. We do not take any legal responsibility.

No part of this book may be reproduced, stored in any retrieval system or transmitted in any form by any means – electronic, mechanical photocopying, recording or otherwise without the prior written permission of the Authors and Publisher.

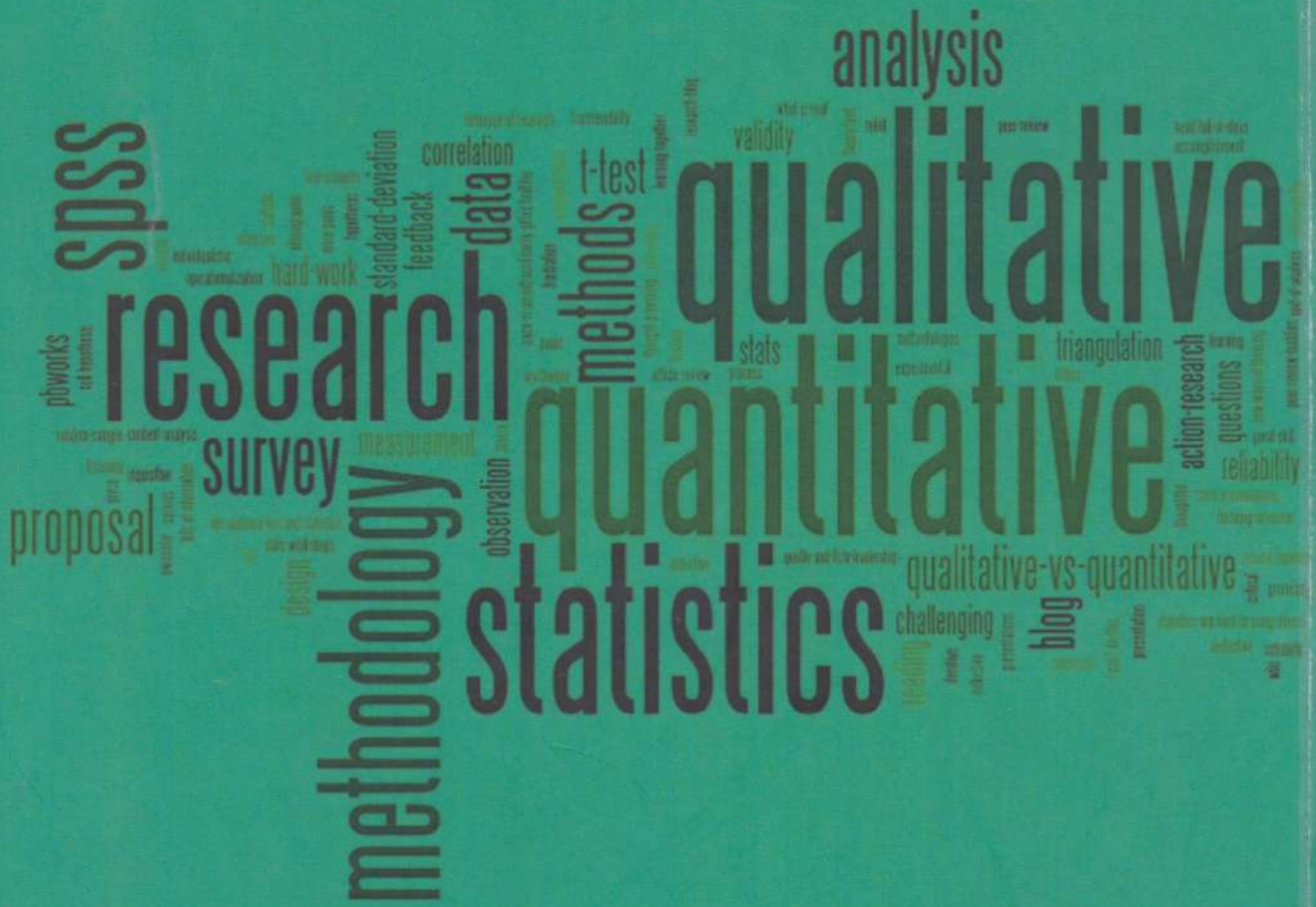
First Edition

Price: Within India : Rs.**140/-**

Typeset by JAZYM Publications

Trichy, India.

Printed in India.


analysis
spss
qualitative
research
methods
data
t-test
correlation
validity
standard-deviation
feedback
hard-work
stats
triangulation
quantitative
action-research
questions
reliability
survey
measurement
observation
proposal
methodology
statistics
qualitative-vs-quantitative
challenging
blog



RESEARCH METHODOLOGY AND SCIENTIFIC WRITING

- A RESEARCHERS' HANDBOOK

Dr. K. Ravichandran
Dr. K. Swaminathan
Dr. A. T. Ravichandran
Dr. C. Ravidhas

RESEARCH METHODOLOGY AND SCIENTIFIC WRITING

- A RESEARCHERS' HANDBOOK

Dr. K. Ravichandran
Associate Professor and Head
PG & Research Department of Physics
AVVM Sri Pushpam College (Autonomous)
Poondi, Thanjavur - 613 503
Tamilnadu, India

Dr. K. Swaminathan
Associate Professor,
PG & Research Department of Physics
RKM Vivekananda College (Autonomous)
Chennai - 600 004
Tamilnadu, India

Dr. A.T. Ravichandran
Associate Professor
PG & Research Department of Physics
National College (Autonomous)
Tiruchirappalli - 620 017
Tamilnadu, India

Dr. C. Ravidhas
Head
PG & Research Department of Physics
Bishop Heber College (Autonomous)
Tiruchirappalli-620 017
Tamilnadu, India.

Published by

JAZYM PUBLICATIONS

Trichy-620 023, India.

Phone: 94435 87233

©2018 JAZYM Publications.

Printing of books passes through many stages – writing, composing, proof reading, printing etc. We try our level best to make the book error free. If any mistakes has inadvertently crept in, we regret it and would be deeply indebted to those who point it out. We do not take any legal responsibility.

No part of this book may be reproduced, stored in any retrieval system or transmitted in any form by any means – electronic, mechanical photocopying, recording or otherwise without the prior written permission of the Authors and Publisher.

ISBN: 978-93-87360-07-5

Second Edition

Price: Within India : Rs.**120/-**

Typeset by JAZYM Publications

Trichy, India.

Printed in India.

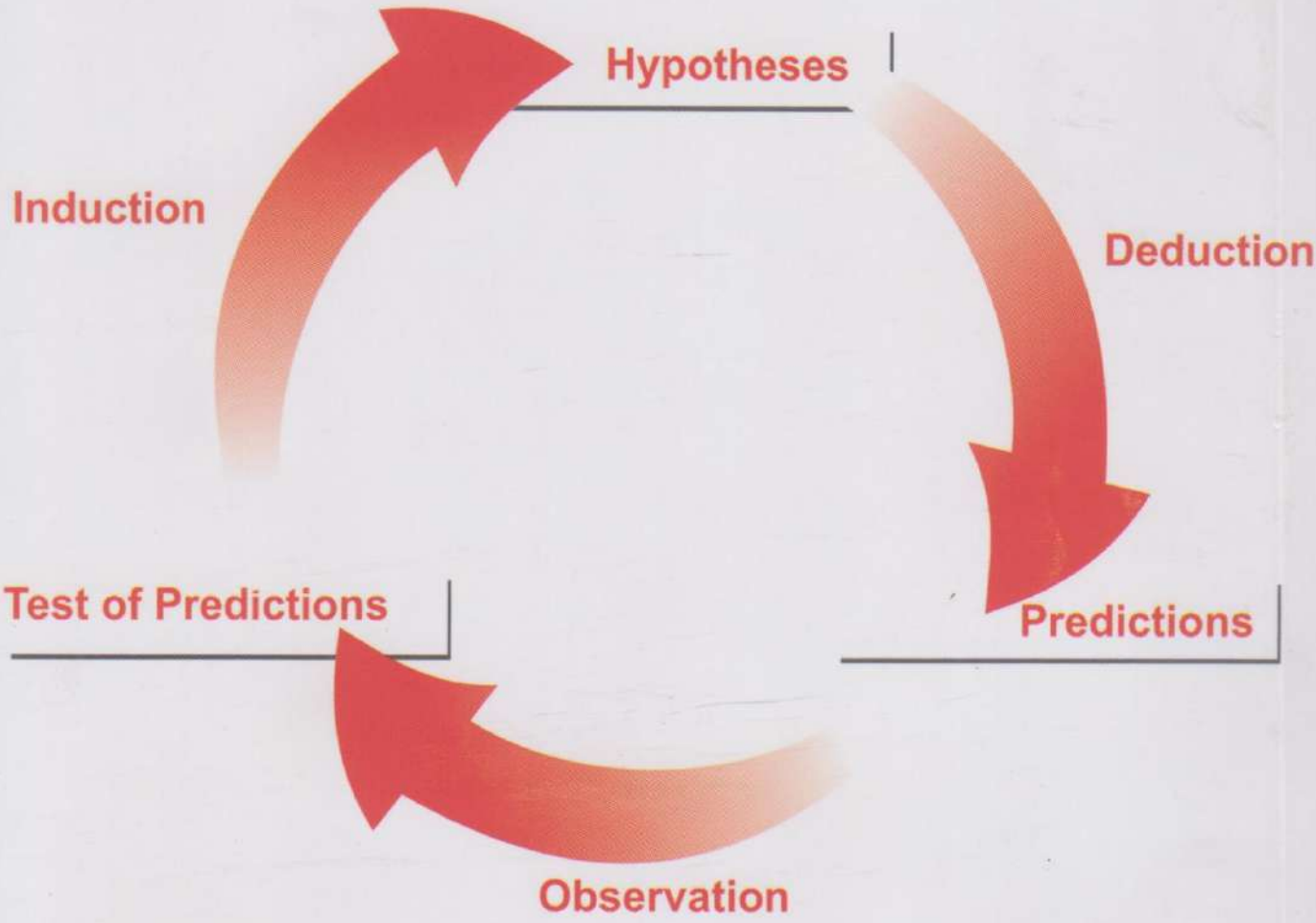
PREFACE

It is of paramount importance that a scholar embarking on research as a career, should have a firsthand knowledge of the various tenets of research such as identifying and stating a problem, formulation of the hypotheses, literature survey, documenting the findings and publishing the theses. The authors, from their long experience of teaching and research, have observed that many researchers fail to fare well when it comes to writing research articles and theses with the right scientific tenor. It is with the aim of guiding and helping out scholars who have difficulty in proper scientific writing that the authors have contemplated bringing out a hand book on scientific writing which they regard as an important facet of the research methodology.

The first chapter discusses definitions and types of research and review of literature. The second and third chapters comprise discussion on significance of data analysis and error handling. The fourth and fifth chapters deal with scientific writing, scientific conventions and the various aspects of thesis writing. Chapters five and six provide information about the effective presentation of research findings and the roles of research supervisors and scholars. The last chapter deals with the procedures for submission of manuscripts to journals.

It is fervently hoped that this book serves the cause of research scholars by inspiring them to carry out the research in a systematic way. Suggestions for improvement are welcome to make this book more useful in the time to come.

K. Ravichandran
K. Swaminathan
A.T. Ravichandran
C. Ravidhas

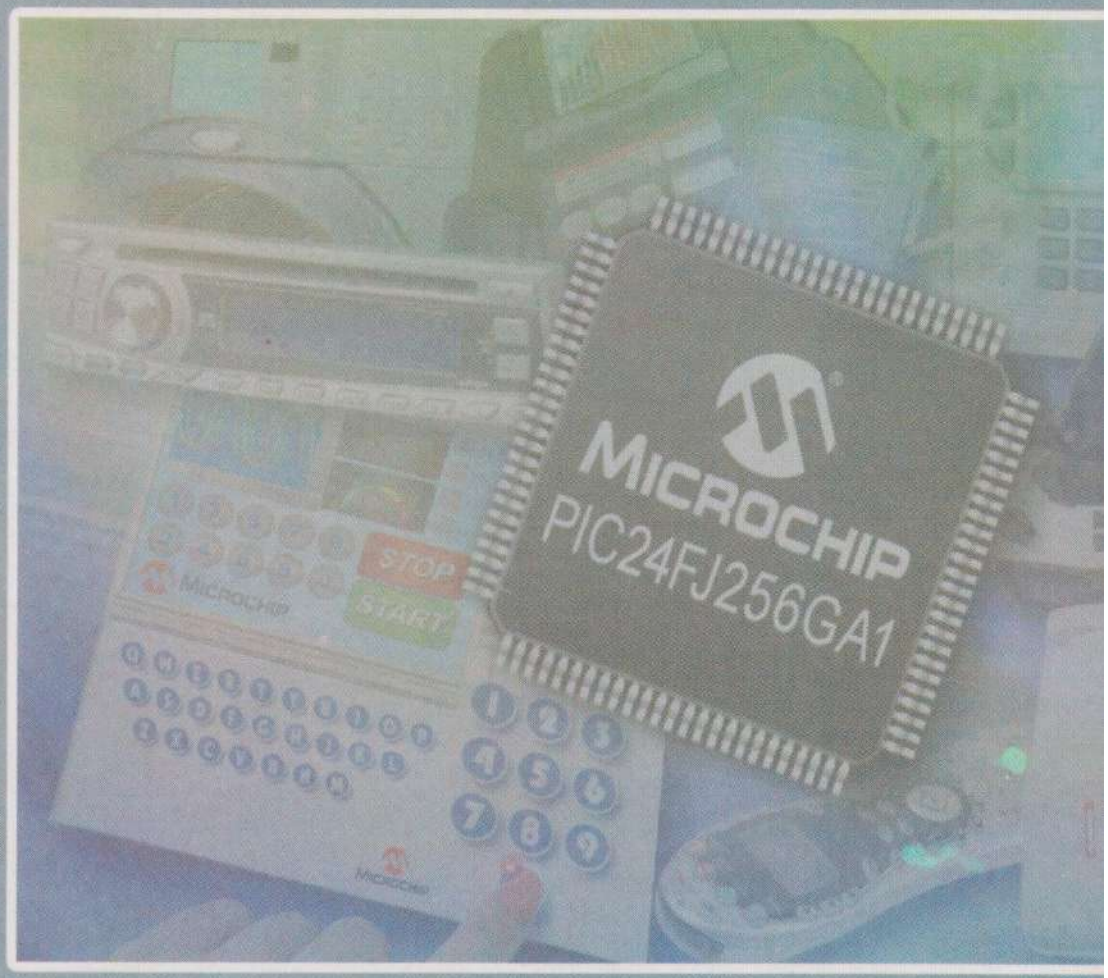


JAZYM PUBLICATION
No.1, Post Office Street
Khajamalai, Tiruchirappalli - 23
Tamil Nadu
Mobile : 94435 87233
Email : jazymtrichy@gmail.com

ISBN 978-93-87360-07-5

Printed @ The Printing House, Try-23. Ph : 0431-2420121

தொடர் அலைவு மற்றும் இலக்க மின்னணுவியல்



முனைவர் சி.பாரி

தமிழ்நாடு மாநில உயர்கல்வி மன்றம்
காமராஜர் சாலை, சென்னை-600 005.

தொடர் அலைவு மற்றும் இலக்க மின்னணுவியல்

முனைவர் சி. பாரி

தமிழ்நாடு மாநில உயர்கல்வி மன்றம்
சென்னை – 600 005.

முதற் பதிப்பு : 2011

பதிப்புரிமை : தமிழ்நாடு மாநில உயர்கல்வி மன்றம்
சென்னை – 600 005

நூலின் பெயர் : தொடர் அலைவு மற்றும் இலக்க மின்னணுவியல்

நூலாசிரியர் : முனைவர் சி. பாரி,
பேராசிரியர், துறைத் தலைவர்
இயற்பியல் துறை,
தேசியக் கல்லூரி,
திருச்சிராப்பள்ளி – 620 001.

மறு ஆய்வு செய்தவர் : முனைவர் ஆர். சபேசன்,
பேராசிரியர், துறைத் தலைவர் (ஓய்வு),
இயற்பியல் துறை,
அழகப்பா பல்கலைக்கழகம்,
காரைக்குடி – 630 003

தமிழ் திருத்தம் செய்தவர் : முனைவர் பா. உதயகுமார்,
இணைப் பேராசிரியர்,
தமிழ்த் துறை,
மாநிலக் கல்லூரி,
சென்னை – 600 005.

விலை : ரூ.112.00

அச்சிட்டோர் : *பாவை பிரிண்டர்ஸ் (பி) லிட்.,*
146, ஜானி ஜான்கான் ரோடு,
இராயப்பேட்டை, சென்னை-600 014.

என்றும் மகாகவி
பாரதி



தொகுப்பாசிரியர்
முனைவர் ச.ஈஸ்வரன்

PUBLICATION HOUSE

என்றும் மகாகவி பாரதி

தொகுப்பாசிரியர்

முனைவர் ச. ஈஸ்வரன்

PUBLICATION HOUSE

நூற்குறிப்பு...

தலைப்பு	:	என்றும் மகாகவி பாரதி
ஆசிரியர்	:	தொகுப்பாசிரியர் முனைவர் ச.ஈஸ்வரன்
முதற்பதிப்பு	:	2022
உரிமை	:	பதிப்பகத்திற்கே
பதிப்பாசிரியர்	:	எஸ்.கௌமாரீஸ்வரி எம்.ஏ., எம்.எல்.ஐ.எஸ்.,
பக்கம்	:	214
பொருள்	:	கட்டுரை
விலை	:	ரூ.220.00
தட்டச்சு	:	ஜெ.ஜெ. டிசைன்ஸ், திருச்சி. 9952034876
அச்சிட்டோர்	:	எ.எஸ்.எக்ஸ் பிரிண்டர்ஸ், சென்னை-1

ENDRUM MAHAKAVI BHARATHI

Compiled By	:	DR.S.EASWARAN
Published on	:	2022
CopyRights ©	:	MJ PUBLICATION HOUSE
Editor	:	S.Gowmareeswari M.A., M.L.I.S.,
Pages	:	214
Subject	:	Non Fiction
Price	:	Rs.220.00
Typeset by	:	JJ Designs, Trichy. 99520 34876
Printed @	:	A.S.X Printers, Chennai 1.
ISBN	:	978-93-91379-37-7
Book ID	:	MJPH 10161

MJ PUBLICATION HOUSE

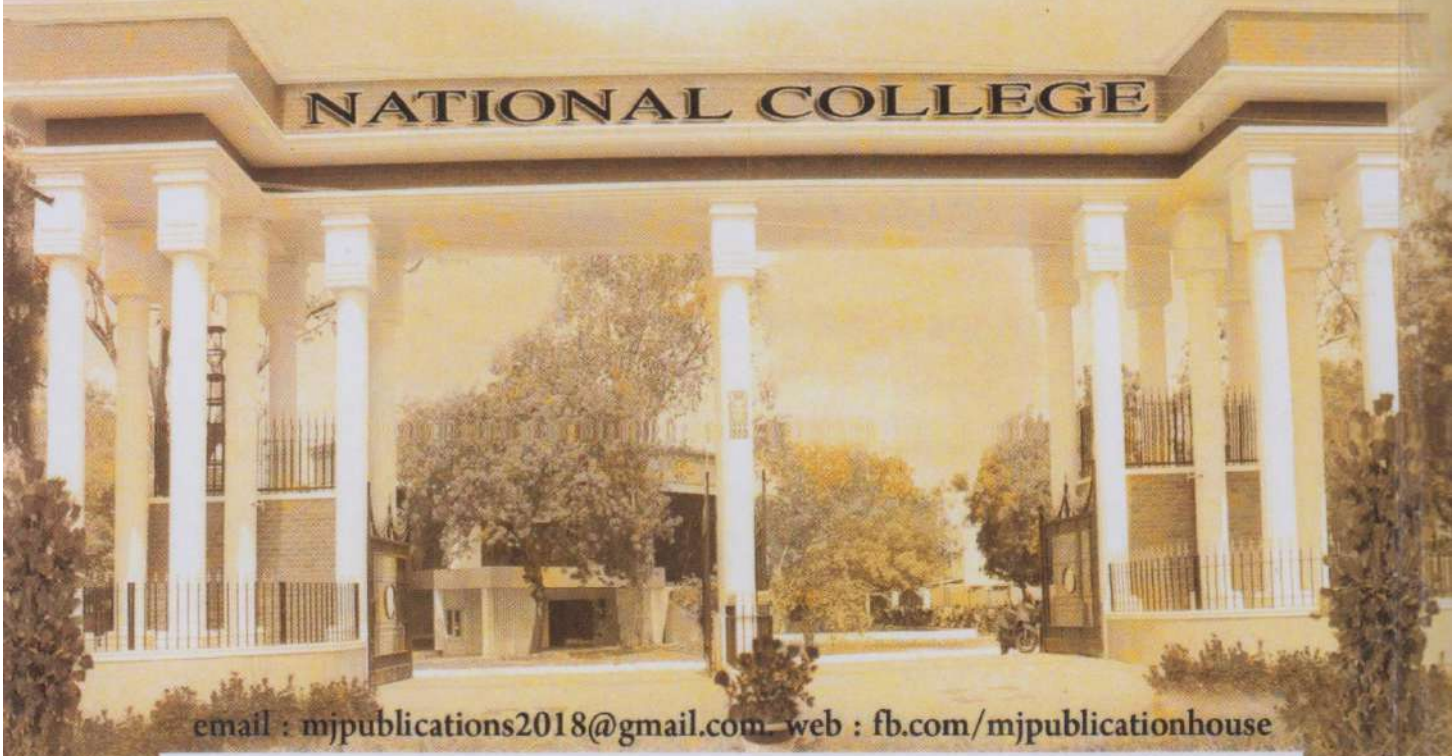
#9, Saint John Church Complex, Rockins Road, Trichy - 1.

Ph : 99434 28994, 0431 4038 994. mjpublications2018@gmail.com.

@mjpublication @facebook.com/mjpublicationhouse

என்றும் மகாகவி பாரதி

தொகுப்பாசிரியர்
முனைவர் ச.ஈஸ்வரன்



email : mjpublications2018@gmail.com web : fb.com/mjpublicationhouse

PUBLICATION HOUSE

ரூபாய்
220

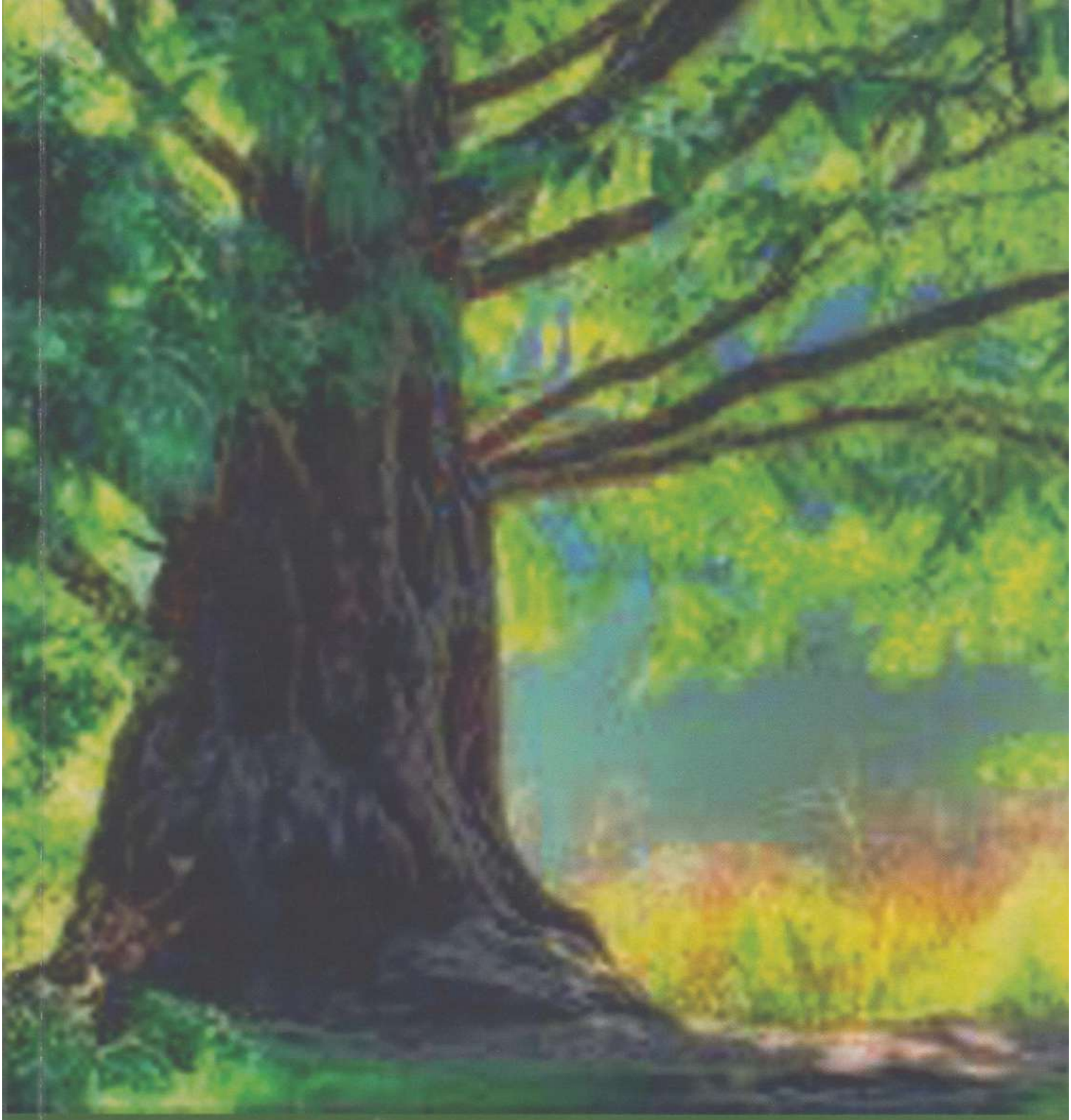
கட்டுரைகள்

MJPH 10161

ISBN 978-93-91379-37-7

9, செ. ஜான் சர்ச் வணிக வளாகம், ராக்கின்ஸ் சாலை,
திருச்சி - 620 001. 0431 4038 994 / 99434 28994.

2022



செம்மொழி நூல்களில் விழுமியங்கள்

முனைவர் ச.ஈஸ்வரன்

செம்மொழி நூல்களில் விழுமியங்கள்

முனைவர் ச.ஈஸ்வரன்
இணைப்பேராசிரியர் & தலைவர்,
தமிழாய்வுத்துறை,
தேசியக்கல்லூரி (தன்னாட்சி),
திருச்சி-620 001.

■ அய்யா நிலையம்

செம்மொழி நூல்களில்
விழுமியங்கள்
ஆசிரியர் : ச.ஈஸ்வரன்©
முதற்பதிப்பு : அக்டோபர் 2020
112 பக்கங்கள் டெம்மி சைஸ்
கணினி அச்சு :
ஸ்ரீ பழனிமுருகன் கம்ப்யூட்டர்ஸ்,
தஞ்சாவூர்- 6.
அச்சு:அன்னை ஆப்செட் பிரிண்டர்ஸ்,
சென்னை-5.
வெளியிட்டோர்:
அய்யா நிலையம்,
மனை எண்.10, ஆரோக்கிய நகர்
முதல் தெரு, E.B. காலனி,
நாஞ்சிக்கோட்டைச் சாலை,
தஞ்சாவூர்-613006.
செல் : 9443007623
விலை : ரூ.120/-

ISBN 978-93-82133-82-7

**SEMMOZHI NOOLKALIL
VIZHUMIYANGGAL**

Author : S.Eswaran©
First Edition : October 2020
112 Pages Demy Size
Typeset by :
Sri Palanimurugan Computers,
Thanjavur - 6.
Printed by : Annai Offset Printers,
Chennai -5.
Published by
AYYA NILAYAM
Plot No.10, Arockiya Nagar
First Street, E.B.Colony,
Nanjikkottai Road,
Thanjavur - 613 006.
Cell : 9443007623
Price: Rs.120/-



முனைவர் ச.ஈஸ்வரன்...

விருதுநகர் மாவட்டம் வத்திராயிருப்பில் பிறந்தவர். திருச்சிராப்பள்ளி தேசியக்கல்லூரியில் இளங்கலை, முதுகலைத் தமிழ் இலக்கியம் பயின்றவர். இதழியல் மற்றும் மக்கள் தகவலியலில் சான்றிதழ் பெற்றவர். ஆய்வியல் நிறைஞர், முனைவர் பட்டங்களைப் பாரதிதாசன் பல்கலைக்கழகத் தமிழ்த்துறையில் ஆய்வு மேற்கொண்டு பெற்றவர்.

இவர் வழிகாட்டுதலில் இதுவரை முப்பத்தெட்டு ஆய்வாளர்கள் முனைவர் பட்டமும், நூற்று இருபது ஆய்வாளர்கள் ஆய்வியல் நிறைஞர் பட்டமும் பெற்றுள்ளனர்.

பாரதிதாசன், பாரதியார், பெரியார், அன்னை தெரசா பல்கலைக் கழகங்களின் சில தன்னாட்சிக் கல்லூரிகளில் தமிழ்ப்பாடத் திட்டக் குழுவிலும், தஞ்சாவூர் தமிழ்ப்பல்கலைக்கழகப் பாடத் திட்டக் குழுவிலும் உறுப்பினராக உள்ளவர்.

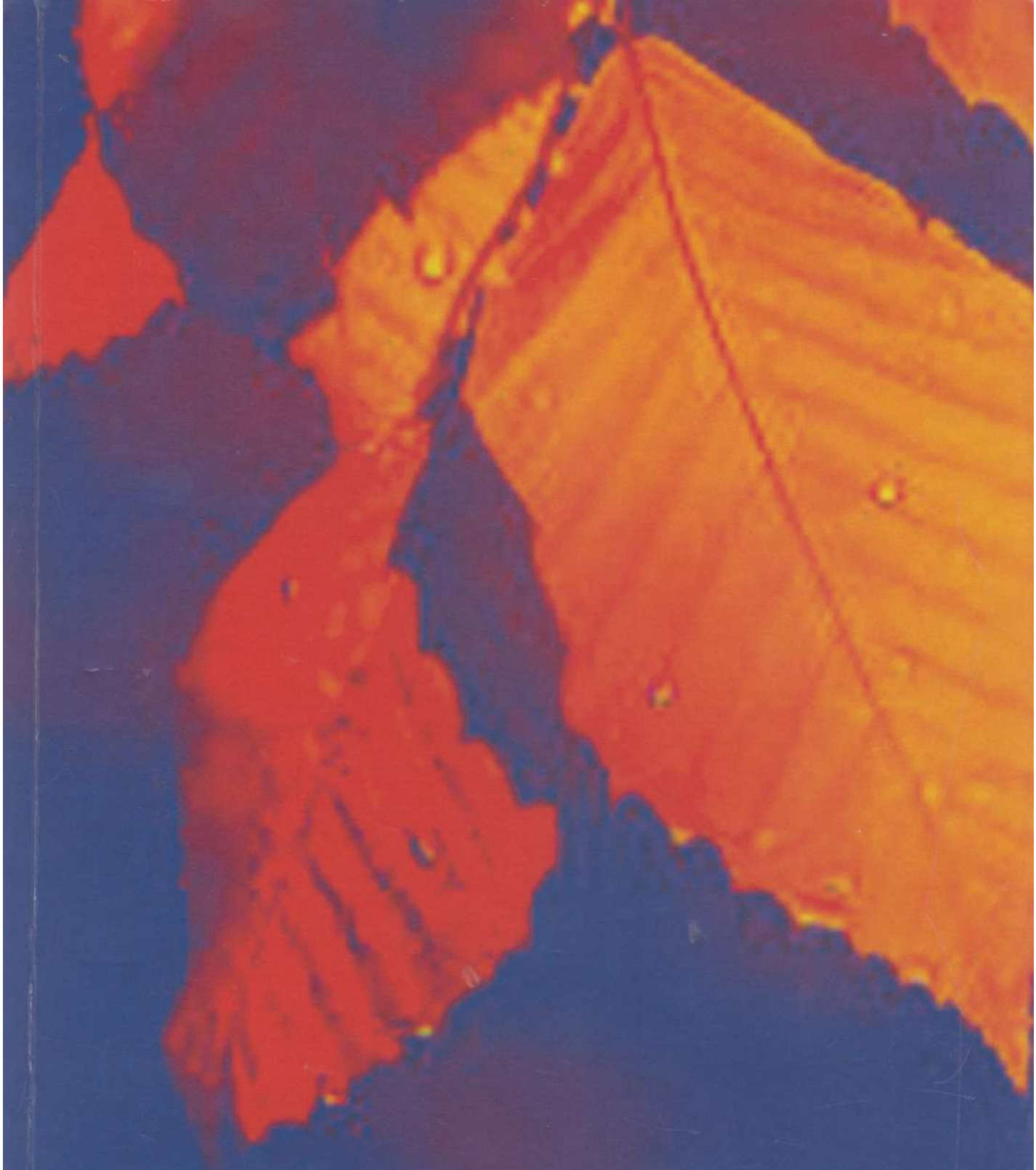
திருச்சி வானொலி, சென்னைப் பொதிகைத் தொலைக்காட்சி எனப் பல்வேறு அமைப்புகளின் இலக்கிய நிகழ்ச்சிகளில் பங்குபெற்று வருபவர்.

பதினைந்துக்கும் மேற்பட்ட நூல்களின் ஆசிரியரான முனைவர் ச.ஈஸ்வரன் தற்போது திருச்சிராப்பள்ளி தேசியக் கல்லூரியின் தமிழாய்வுத் துறையில் இணைப்பேராசிரியர் மற்றும் தலைவராகப் பணியாற்றி வருகிறார்.

ISBN 978-93-82133-82-7

9 789382 133827

அய்யா நிலையம்



செவ்வியல் இணர்

முனைவர் ச.ஈஸ்வரன்

செவ்வியல் இணர்

முனைவர் ச.ஈஸ்வரன்
இணைப்பேராசிரியர் & தலைவர்,
தமிழாய்வுத்துறை,
தேசியக்கல்லூரி (தன்னாட்சி),
திருச்சி-620 001.

■ அய்யா நிலையம்

செவ்வியல் இணர்
ஆசிரியர் : ச.ஈஸ்வரன்©
முதற்பதிப்பு : அக்டோபர் 2020
144 பக்கங்கள் டெம்மி சைஸ்
கணினி அச்சு :
ஸ்ரீ பழனிமுருகன் கம்ப்யூட்டர்ஸ்,
தஞ்சாவூர்- 6.
அச்சு:அன்னை ஆப்செட் பிரிண்டர்ஸ்,
சென்னை-5.
வெளியிட்டோர்:
அய்யா நிலையம்,
மனை எண்.10, ஆரோக்கிய நகர்
முதல் தெரு, E.B. காலனி,
நாஞ்சிக்கோட்டைச் சாலை,
தஞ்சாவூர்-613006.
செல் : 9443007623
விலை : ரூ.140/-

ISBN 978-93-82133-89-6

SEVVIYAL INAR
Author : S.Eswaran©
First Edition : October 2020
144 Pages Demy Size
Typeset by :
Sri Palanimurugan Computers,
Thanjavur - 6.
Printed by : Annai Offset Printers,
Chennai -5.
Published by
AYYA NILAYAM
Plot No.10, Arockiya Nagar
First Street, E.B.Colony,
Nanjikkottai Road,
Thanjavur - 613 006.
Cell : 9443007623
Price: Rs.140/-



முனைவர் **ச.ஈஸ்வரன்...**

விருதுநகர் மாவட்டம் வத்திராயிருப்பில் பிறந்தவர். திருச்சிராப்பள்ளி தேசியக்கல்லூரியில் இளங்கலை, முதுகலைத் தமிழ் இலக்கியம் பயின்றவர். இதழியல் மற்றும் மக்கள் தகவலியலில் சான்றிதழ் பெற்றவர். ஆய்வியல் நிறைஞர், முனைவர் பட்டங்களைப் பாரதிதாசன் பல்கலைக்கழகத் தமிழ்த்துறையில் ஆய்வு மேற்கொண்டு பெற்றவர்.

இவர் வழிகாட்டுதலில் இதுவரை முப்பத்தெட்டு ஆய்வாளர்கள் முனைவர் பட்டமும், நூற்று இருபது ஆய்வாளர்கள் ஆய்வியல் நிறைஞர் பட்டமும் பெற்றுள்ளனர்.

பாரதிதாசன், பாரதியார், பெரியார், அன்னை தெரசா பல்கலைக் கழகங்களின் சில தன்னாட்சிக் கல்லூரிகளில் தமிழ்ப்பாடத் திட்டக் குழுவிலும், தஞ்சாவூர் தமிழ்ப்பல்கலைக்கழகப் பாடத் திட்டக் குழுவிலும் உறுப்பினராக உள்ளவர்.

திருச்சி வானொலி, சென்னைப் பொதிகைத் தொலைக்காட்சி எனப் பல்வேறு அமைப்புகளின் இலக்கிய நிகழ்ச்சிகளில் பங்குபெற்று வருபவர்.

பதினைந்துக்கும் மேற்பட்ட நூல்களின் ஆசிரியரான முனைவர் ச.ஈஸ்வரன் தற்போது திருச்சிராப்பள்ளி தேசியக் கல்லூரியின் தமிழாய்வுத் துறையில் இணைப்பேராசிரியர் மற்றும் தலைவராகப் பணியாற்றி வருகிறார்.

ISBN 978-93-82133-89-6

9 789382 133896

அய்யா நிலையம்

சோழமண்டலமும் இலக்கியவளமும்

நூற்றாண்டு விழாவின் ஒரு பகுதியாக

தேசியக்கல்லூரித் தமிழாய்வுத்துறை
நடத்தும்

பன்னாட்டுக் கருத்தரங்கம்

01 மார்ச் 2019 (திருவள்ளுவராண்டு 2050)



பதிப்பாசிரியர்
முனைவர் ச. ஈஸ்வரன்

DR V KRISHNAMURTHY
Educational Foundation
TIRUCHIRAPPALLI
Since 1919

தமிழாய்வுத்துறை
தேசியக்கல்லூரி (தன்னாட்சி)

ஆற்றல்சால் தகுதி பெற்றது
(தேசியதர மதிப்பீட்டில் A+(3.61) தகுதி பெற்றது)
திருச்சிராப்பள்ளி-620 001.

சோழ மண்டலமும் இலக்கிய வளமும்

நூற்றாண்டு விழாவின் ஒரு பகுதியாக...

தேசியக்கல்லூரித் தமிழாய்வுத்துறை

நடத்திய

பன்னாட்டுக் கருத்தரங்கம்

01 மார்ச் 2019 (திருவள்ளுவராண்டு 2050)

பதிப்பாசிரியர்

முனைவர் ச. ஈஸ்வரன்

Since 1919

DR V KRISHNAMURTHY
Educational Foundation

தமிழாய்வுத்துறை

தேசியக்கல்லூரி (தன்னாட்சி)

ஆற்றல்சால் தகுதி பெற்றது

தேசியத் தர மதிப்பீட்டில் 'ஏ+' (3.61) தகுதி பெற்றது

திருச்சிராப்பள்ளி- 620 001.

நூல் விளக்கக் குறிப்பு

நூலின் பெயர் : **சோழ மண்டலமும் இலக்கிய வளமும்**

பதிப்பாசிரியர் : முனைவர் **ச.ஈஸ்வரன்**

மொழி : தமிழ்

பொருள் : ஆய்வுக் கட்டுரைகள்

பதிப்பாண்டு : மார்ச், 2019

நூலின் அளவு : டெமி

பக்கங்கள் : (xxvi) + 586 = 612

நூலின் கட்டு : சாதாரணம்

அச்சுத்தாள் விவரம் : மேப்லித்தோ

உரிமை : தமிழாய்வுத்துறை,
தேசியக்கல்லூரி (தன்னாட்சி).
திருச்சிராப்பள்ளி-620 001.

அச்சிட்டோர் : **தி பிரிண்டிங் ஹவுஸ்,**
காஜாமலை, திருச்சி-23.
போன் : 0431-2420121

வெளியீடு : ஜாமி பப்ளிகேஷன்ஸ்
திருச்சி -23.

ISBN : 978-93-87354-23-4

நூற்றாண்டு விழாவின் ஒரு பகுதியாக...

தேசியக் கல்லூரி, தமிழாய்வுத்துறையில் 2019, மார்ச் 01ஆம் நாள் நடத்தப்பெற்ற பன்னாட்டுக் கருத்தரங்கின் வெளியீடு

தனிச்சுற்றுக்கு மட்டும்

ISBN 978-93-87354-23-4

Jami Publications
No.6, Race Course Road
Khajamalai, Tiruchirappalli - 23
Tamil Nadu, India
Mobile : 0 95972 25518
Email : jamitrichy@gmail.com

Print @ The Printing House, Try-23.Ph : 2420121

தமிழிலக்கியங்களில் மேலாண்மைச் சிந்தனைகள்

தேசியக் கருத்தரங்கம்

(பல்கலைக்கழக நிதி நல்கைக்குழுவின்
தன்னாட்சி நிதி உதவியுடன்)

பிப்ரவரி 12, 2016
திருவள்ளுவராண்டு 2047-தை 29

பதிப்பாசிரியர்

முனைவர் ச. ஈஸ்வரன்

தமிழாய்வுத் துறை

தேசியக் கல்லூரி (தன்னாட்சி)

ஆற்றல்சார் தகுதி பெற்றது

தேசியத் தர மதிப்பீட்டில் 'ஏ' தகுதி பெற்றது

திருச்சிராப்பள்ளி - 620 001.

தமிழிலக்கியங்களில் மேலாண்மைச் சிந்தனைகள்

(பல்கலைக்கழக நிதி நல்கைக்குழுவின்
தன்னாட்சி நிதி உதவியுடன்)

பிப்ரவரி 12, 2016

திருவள்ளுவராண்டு 2047 - தை 29

தமிழாய்வுத் துறை,

தேசியக் கல்லூரி (தன்னாட்சி),

ஆற்றல்சார் தகுதி பெற்றது

தேசியத் தர மதிப்பீட்டில் 'ஏ' தகுதி பெற்றது

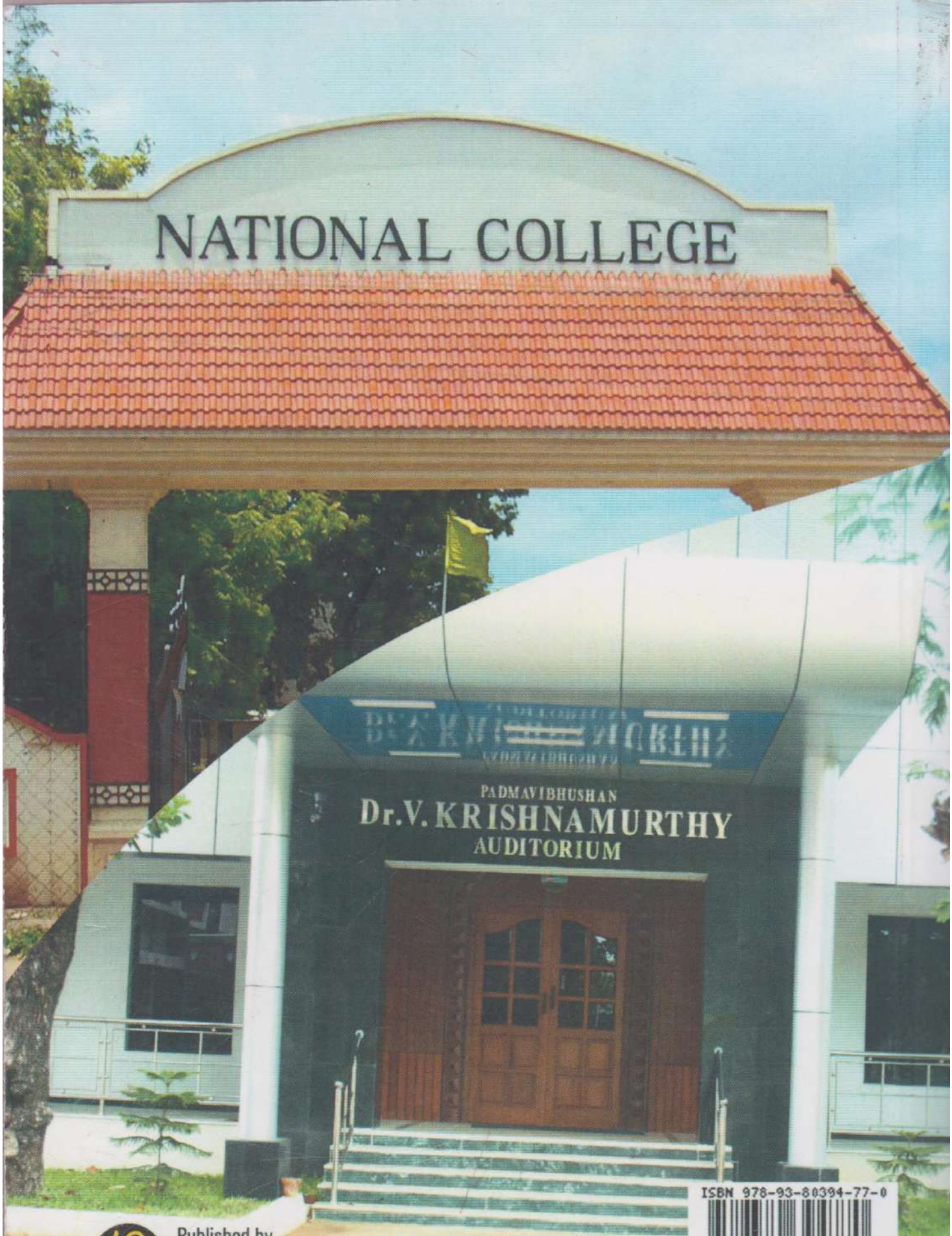
திருச்சிராப்பள்ளி - 620 001.

நூல் விளக்கக் குறிப்பு

நூலின் பெயர்	:	**தமிழிலக்கியங்களில் மேலாண்மைச் சிந்தனைகள்**
பதிப்பாசிரியர்	:	முனைவர் **ச.ஈஸ்வரன்**
மொழி	:	தமிழ்
பொருள்	:	இலக்கியக் கட்டுரைகள்
பதிப்பாண்டு	:	பிப்ரவரி 2016
நூலின் அளவு	:	டெமி
நூலின் கட்டு	:	சாதாரணம்
அச்சுத்தாள் விவரம்	:	18.6 மேப்லித்தோ
உரிமை	:	தமிழாய்வுத்துறை தேசியக்கல்லூரி (தன்னாட்சி). திருச்சிராப்பள்ளி-620 001.
அச்சிட்டோர்	:	**தி பிரிண்டிங் ஹவுஸ்,** காஜாமலை, திருச்சி-23. போன் : 0431-2420121
வெளியீடு	:	**இராஜா பப்ளிகேஷன்ஸ்** திருச்சி-23. செல் : 96005 35241
ISBN	:	978-93-80394-77-0
ISBN குறியீடு	:	ISBN 978-93-80394-77-0 9 789380 394770

தேசியக் கல்லூரி, தமிழாய்வுத் துறையில் 2016, பிப்ரவரி 12ஆம் நாள் நடத்தப் பெற்ற தேசியக் கருத்தரங்கின் வெளியீடு

தனிச்சுற்றுக்கு மட்டும்



ISBN 978-93-80394-77-0

9 789380 394770

Published by
RAJA PUBLICATIONS
No. 10 (Upstair), Ibrahim Nagar, Khajamalai,
Tiruchirappalli - 620 023, Tamil Nadu, India.
Mobile : 9600535241
Website : www.rajapublications.com

Print @ The Printing House, Try:23.Ph:2420121

தமிழ் இலக்கிய வரலாறு

முனைவர். ச. ஈஸ்வரன்

நிர்மலா பதிப்பகம்

தமிழ் இலக்கிய வரலாறு

முனைவர் ச. ஈஸ்வரன்

எம்.ஏ., எம்ஃபில்., பிஜிடிஜேஎம்சி., பிஎச்.டி.,

இணைப்பேராசிரியர் மற்றும் துறைத்தலைவர்,

தமிழாய்வுத்துறை, தேசியக்கல்லூரி (தன்னாட்சி)

திருச்சிராப்பள்ளி - 620 001.

நிர்மலா பதிப்பகம்

மதுரை - 1

பதிப்பு : ஜூலை 2017

பதிப்புரிமை : நிர்மலா பதிப்பகம் ©

விலை : ரூ. 150/-

ISBN No: 978-81-924217-9-7

வெளியீடு:

நிர்மலா பதிப்பகம்

37-A, வடக்காவணி மூல வீதி,

மதுரை - 625 001.

செல்: 9976648822

தமிழ் இலக்கியங்களில் பல்துறைச் சிந்தனைகள்

பல்கலைக்கழக நிதிநல்கைக் குழுவின்
தன்னாட்சி நிதி உதவியுடன் நடத்தப்பெறும்

தேசியக்கருத்தரங்கம்

நாள் : 15.12.2017, வெள்ளிக்கிழமை.



பதிப்பாசிரியர்

முனைவர் ச. ஈஸ்வரன்

தமிழாய்வுத்துறை

தேசியக்கல்லூரி (தன்னாட்சி)

(தேசியதர மதிப்பீட்டில் A+(3.61) ஆற்றல்சால் தகுதி வற்றது)

திருச்சிராப்பள்ளி-620 001.

தமிழ் இலக்கியங்களில் பல்துறைச் சிந்தனைகள்

பல்கலைக்கழக நிதிநல்கைக் குழுவின்
தன்னாட்சி நிதி உதவியுடன்
15-12-2017 அன்று நடைபெற்ற
தேசியக்கருத்தரங்கம்

பதிப்பாசிரியர்
முனைவர் **ச. ஈஸ்வரன்**

தமிழாய்வுத்துறை
தேசியக்கல்லூரி (தன்னாட்சி - ஏ⁺)
திருச்சிராப்பள்ளி – 620 001.

நூல் விளக்கக் குறிப்பு

நூலின் பெயர் : **தமிழ் இலக்கியங்களில் பல்துறைச் சிந்தனைகள்**

பதிப்பாசிரியர் : முனைவர் **ச.ஈஸ்வரன்**

மொழி : தமிழ்

பொருள் : இலக்கியக் கட்டுரைகள்

பதிப்பு : முதல்

பதிப்பாண்டு : டிசம்பர், 2017.

நூலின் அளவு : டெமி

நூலின் கட்டு : சாதாரணம்

அச்சுத்தாள் விவரம் : மேப்லித்தோ

உரிமை : தமிழாய்வுத்துறை
தேசியக்கல்லூரி (தன்னாட்சி).
திருச்சிராப்பள்ளி-620 001.

அச்சிட்டோர் : **தி பிரிண்டிங் ஹவுஸ்,**
காஜாமலை, திருச்சி-23.
போன் : 0431-2420121

வெளியீடு : ஜாமி பப்ளிகேஷன்ஸ்
திருச்சி -23.

ISBN : 978-93-87354-03-6

தேசியக் கல்லூரி, தமிழாய்வுத் துறையில் 2017, டிசம்பர் 15 ஆம் நாள் நடத்தப்பெற்ற தேசியக்கருத்தரங்கின் வெளியீடு

தனிச்சுற்றுக்கு மட்டும்



Jami Publications
No.6, Race Course Road
Khajamalai, Tiruchirappalli - 23
Tamil Nadu, India
Mobile : 0 95972 25518
Email : jamitrichy@gmail.com

ISBN 978-93-87354-03-6

Print @ The Printing House, Try-23.Ph : 2420121

தமிழ் இலக்கியங்களில் வாழ்வியல் விழுமியங்கள்

ஒருநாள் தேசியக்கருத்தரங்கம்

26 பிப்ரவரி 2020

பதிப்பாசிரியர்

முனைவர் ச. ஈஸ்வரன்

NATIONAL COLLEGE TRICHINOPOLY

Since 1919

DR V KRISHNAMURTHY Educational Foundation

தமிழாய்வுத்துறை

தேசியக்கல்லூரி (தன்னாட்சி)

ஆற்றல்சால் தகுதி பெற்றது

(தேசியதர மதிப்பீட்டில் A+ (3.61) தகுதி பெற்றது)

திருச்சிராப்பள்ளி-620 001.

தமிழ் இலக்கியங்களில் வாழ்வியல் விழுமியங்கள்

பல்கலைக்கழக நிதிநல்கைக் குழுவின்
தன்னாட்சி நிதி உதவியுடன் நிகழ்த்தப்பெறும்
தேசியக்கருத்தரங்கம்

26 பிப்ரவரி 2020 (திருவள்ளுவராண்டு 2051)

பதிப்பாசிரியர்
முனைவர் ச. ஈஸ்வரன்

NATIONAL COLLEGE TRICHINOPOLY
Since 1919

DR V KRISHNAMURTHY
Educational Foundation



தமிழாய்வுத்துறை
தேசியக்கல்லூரி (தன்னாட்சி)
ஆற்றல்சால் தகுதி பெற்றது
தேசியத் தர மதிப்பீட்டில் 'ஏ+' (3.61) தகுதி பெற்றது
திருச்சிராப்பள்ளி- 620 001.

நூல் விளக்கக் குறிப்பு

நூலின் பெயர் : **தமிழ் இலக்கியங்களில் வாழ்வியல் விழுமியங்கள்**

பதிப்பாசிரியர் : முனைவர் **ச.ஈஸ்வரன்**

மொழி : தமிழ்

பொருள் : ஆய்வுக்கட்டுரைகள்

பதிப்பாண்டு : பிப்ரவரி, 2020

நூலின் அளவு : டெமி

பக்கங்கள் : (xvi) + 300 = 316

நூலின் கட்டு : சாதாரணம்

அச்சுத்தாள் விவரம் : மேப்லித்தோ

உரிமை : தமிழாய்வுத்துறை,
தேசியக்கல்லூரி (தன்னாட்சி).
திருச்சிராப்பள்ளி-620 001.

அச்சிட்டோர் : **தி பிரிண்டிங் ஹவுஸ்,**
காஜாமலை, திருச்சி-23.
போன் : 0431-2420121

வெளியீடு : ஜாஸிம் பப்ளிகேஷன்ஸ்
திருச்சி -23.

ISBN : 978-93-87360-55-6

தேசியக் கல்லூரி, தமிழாய்வுத்துறையில் 2020, பிப்ரவரி 26-ஆம் நாள் நடத்தப்பெற்ற தேசியக் கருத்தரங்கின் வெளியீடு

தனிச்சுற்றுக்கு மட்டும்



P PUBLICATIONS
No.1, Post Office Street
Khajamalai, Trichy - 23
Tamil Nadu
Mobile : 94435 87233
Email : jazymtrichy@gmail.com

ISBN 978-93-87360-55-6
9 789387 360556 >

Print @ The Printing House, Try-23.Ph : 2420121

பன்முக நோக்கில் மகாகவி

(பாரதியார் நினைவு நூற்றாண்டு விழாவின் ஒரு பகுதியாகத் தேசியக் கல்லூரித் தமிழாய்வுத்துறைப் பேராசிரியர்கள் எழுதிய கட்டுரைகளின் தொகுப்பு)



பதிப்பாசிரியர்

முனைவர் ச. ஈஸ்வரன்

NATIONAL COLLEGE TRICHINOPOLY Estd. 1919

DR V KRISHNAMURTHY Educational Foundation TIRUCHIRAPPALLI

தமிழாய்வுத்துறை

தேசியக்கல்லூரி (தன்னாட்சி)

ஆற்றல்சால் தகுதி பெற்றது

(தேசியத்தர மதிப்பீட்டில் A+ (3.61) தகுதி பெற்றது)

திருச்சிராப்பள்ளி-620 001.

பன்முக நோக்கில் மகாகவி

தேசியக் கல்லூரி, தமிழாய்வுத்துறையில் 2021, செப்டம்பர் 09-ஆம் நாள் நடத்தப்பெற்ற மகாகவி பாரதியார் நினைவு நூற்றாண்டு விழா - வெளியீடு

9 செப்டம்பர் 2021

திருவள்ளுவராண்டு 2052

பதிப்பாசிரியர்

முனைவர் ச. ஈஸ்வரன்

Since 1919

DR V KRISHNAMURTHY
Educational Foundation

தமிழாய்வுத்துறை

தேசியக்கல்லூரி (தன்னாட்சி)

ஆற்றல்சால் தகுதி பெற்றது

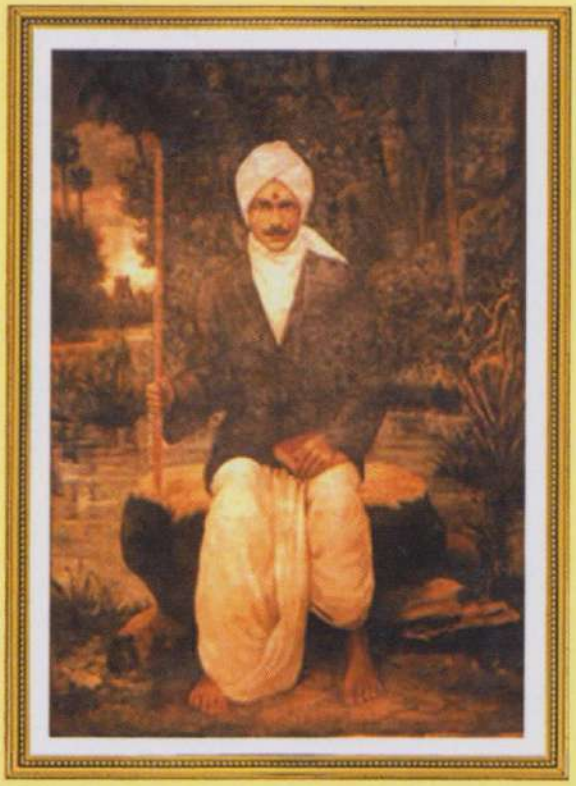
தேசியத் தர மதிப்பீட்டில் 'ஏ+' (3.61) தகுதி பெற்றது

திருச்சிராப்பள்ளி- 620 001.

நூல் விளக்கக் குறிப்பு

நூலின் பெயர்	:	**பன்முக நோக்கில் மகாகவி**
பதிப்பாசிரியர்	:	முனைவர் **ச.ஈஸ்வரன்**
மொழி	:	தமிழ்
பொருள்	:	ஆய்வுக்கட்டுரைகள்
பதிப்பாண்டு	:	2021
நூலின் அளவு	:	டெமி
பக்கங்கள்	:	(xiv) + 182 = 196
நூலின் கட்டு	:	சாதாரணம்
அச்சுத்தாள் விவரம்	:	மேப்லித்தோ
உரிமை	:	தமிழாய்வுத்துறை, தேசியக்கல்லூரி (தன்னாட்சி). திருச்சிராப்பள்ளி-620 001.
அச்சிட்டோர்	:	**தி பிரிண்டிங் ஹவுஸ்,** காஜாமலை, திருச்சி-23. போன் : 0431-2420121
ISBN	:	978-93-91563-21-9

978-93-91563-21-9



பாரதியின் ஓவியம் தீட்டிய தேசியக் கல்லூரி மாணவர்

தமிழுக்கென்றும் தமிழ்நாட்டிற்கென்றும் முகப்புத்தகமாக விளங்கும் நம் பாரதிக்கு அடையாளமாக திரு. ஆரியா என்கிற பாஷ்யம் ஐயங்கார் தீட்டிய முத்திரையான முண்டாசு ஓவியம். இவ்வோவியம் தமிழ்நாடு அரசால் அங்கீகரிக்கப்பட்டு சென்னையில் உள்ள தமிழ்நாடு அரசு அருங்காட்சியகத்தில் அனைவரின் பார்வைக்காக வைக்கப்பட்டுள்ளது.

தன்னிகரற்ற நூற்றாண்டின் பெருமை – தடித்த முண்டாசும்
துடிக்கும் மீசையுமே!

"என்று தணியும் இந்தச் சுதந்திர தாகம்" என்று ஆர்ப்பரித்த பாரதப் புதல்வனாம் நம் பாரதிக்கு "தேசிய"த்தின் மீது எந்த அளவு உரிமையும் உவகையும் உள்ளதோ அதற்கீடான பற்றும் பக்தியும் அந்த சகாப்தத்தையே இந்த உலகுக்கு முன்மொழிந்த தேசியக் கல்லூரிக்கும் உண்டு. தேசியக்கவி என்ற பெயரைச் சொன்னாலே நம் கண்முன் வருவது அந்த விவேகம் ததும்பிய முண்டாசும், வீரம் முறுக்கிய மீசையும் தான். 'நிற்பதுவே நடப்பதுவே.. உம்முள் ஆழ்ந்த பொருளில்லையோ' என பாட்டுரைத்த கவிக்கு "முண்டாசும் மீசையும் தான். எம் பாரதம் போற்றும் பாரதி" எனப் பொருளுரைத்த ஓவியத்தைத் தீட்டிய பெருமை நம் தேசியக் கல்லூரியின் முன்னாள் மாணவரும், சுதந்திரப் போராட்டத் தியாகியுமான திரு. ஆரியா என்கிற பாஷ்யம் ஐயங்கார் அவர்களையே சாரும்.

எண்ணம்:
முனைவர் ச. செந்தில் குமார்
உதவிப் பேராசிரியர்
தாவரவியல் துறை, தேசியக்கல்லூரி (தி)

எழுத்து:
வருணா குமரவேல்
உதவிப் பேராசிரியர்,
தொழில்நுட்பவியல் மற்றும் நுண்ணுயிரியல் துறை

ISBN 978-93-91563-21-9

PJ JAZYM PUBLICATIONS
No.1, Post Office Street
Khajamalai, Trichy - 23
Tamil Nadu
Mobile : 94435 87233
Email : jazymtrichy@gmail.com

9 789391 563219

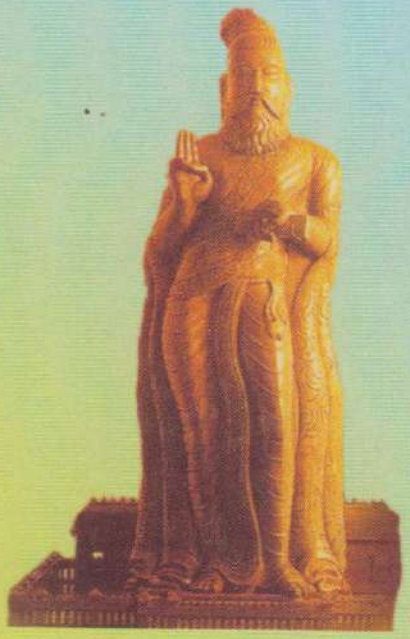
Print @ The Printing House, Try - 23. Ph: 0431-2420121

பன்னோக்குப் பார்வையில் திருமந்திரம்

தேசியக்கல்லூரித் தமிழாய்வுத்துறையும்
திருமந்திரம் அருட்சபை அறக்கட்டளையும்
இணைந்து நடத்தும்

ஒருநாள் தேசியக்கருத்தரங்கம்

26 செப்டம்பர் 2018 (திருவள்ளுவராண்டு 2049)



பதிப்பாசிரியர்
முனைவர் ச. ஈஸ்வரன்

NATIONAL COLLEGE
TRICHINOPOLY
Since 1919

VASI SIVASI
PRANAYAM NAASI

100
NATIONAL COLLEGE

தமிழாய்வுத்துறை
தேசியக்கல்லூரி (தன்னாட்சி)

ஆற்றல்சால் தகுதி பெற்றது
(தேசியதர மதிப்பீட்டில் A+ (3.61) தகுதி பெற்றது)
திருச்சிராப்பள்ளி-620 001.

பன்னோக்குப் பார்வையில் திருமந்திரம்

தேசியக்கல்லூரித் தமிழாய்வுத்துறையும்
திருமந்திரம் அருட்சபை அறக்கட்டளையும்
இணைந்து நடத்தும்

ஒருநாள் தேசியக் கருத்தரங்கம்

26 செப்டம்பர் 2018 (திருவள்ளுவராண்டு 2049)

பதிப்பாசிரியர்
முனைவர் ச. ஈஸ்வரன்

Since 1919

தமிழாய்வுத்துறை

தேசியக்கல்லூரி (தன்னாட்சி)

ஆற்றல்சால் தகுதி பெற்றது
தேசியத் தர மதிப்பீட்டில் 'ஏ+' (3.61) தகுதி பெற்றது
திருச்சிராப்பள்ளி- 620 001.

நூல் விளக்கக் குறிப்பு

நூலின் பெயர் : **பன்னோக்குப் பார்வையில் திருமந்திரம்**

பதிப்பாசிரியர் : முனைவர் ச.ஈஸ்வரன்

மொழி : தமிழ்

பொருள் : இலக்கியக் கட்டுரைகள்

பதிப்பு : முதல்

பதிப்பாண்டு : செப்டம்பர், 2018

நூலின் அளவு : டெமி

நூலின் கட்டு : சாதாரணம்

அச்சுத்தாள் விவரம் : மேப்லித்தோ

உரிமை : தமிழாய்வுத்துறை,
தேசியக்கல்லூரி (தன்னாட்சி).
திருச்சிராப்பள்ளி-620 001.

அச்சிட்டோர் : **தி பிரிண்டிங் ஹவுஸ்,**
காஜாமலை, திருச்சி-23.
போன் : 0431-2420121

வெளியீடு : ஜாமி பப்ளிகேஷன்ஸ்
திருச்சி -23.

ISBN : 978-93-87354-16-6

தேசியக் கல்லூரி, தமிழாய்வுத்துறையில் 2018, செப்டம்பர் 26 ஆம் நாள் நடத்தப்பெற்ற தேசியக்கருத்தரங்கின் வெளியீடு

தனிச்சுற்றுக்கு மட்டும்



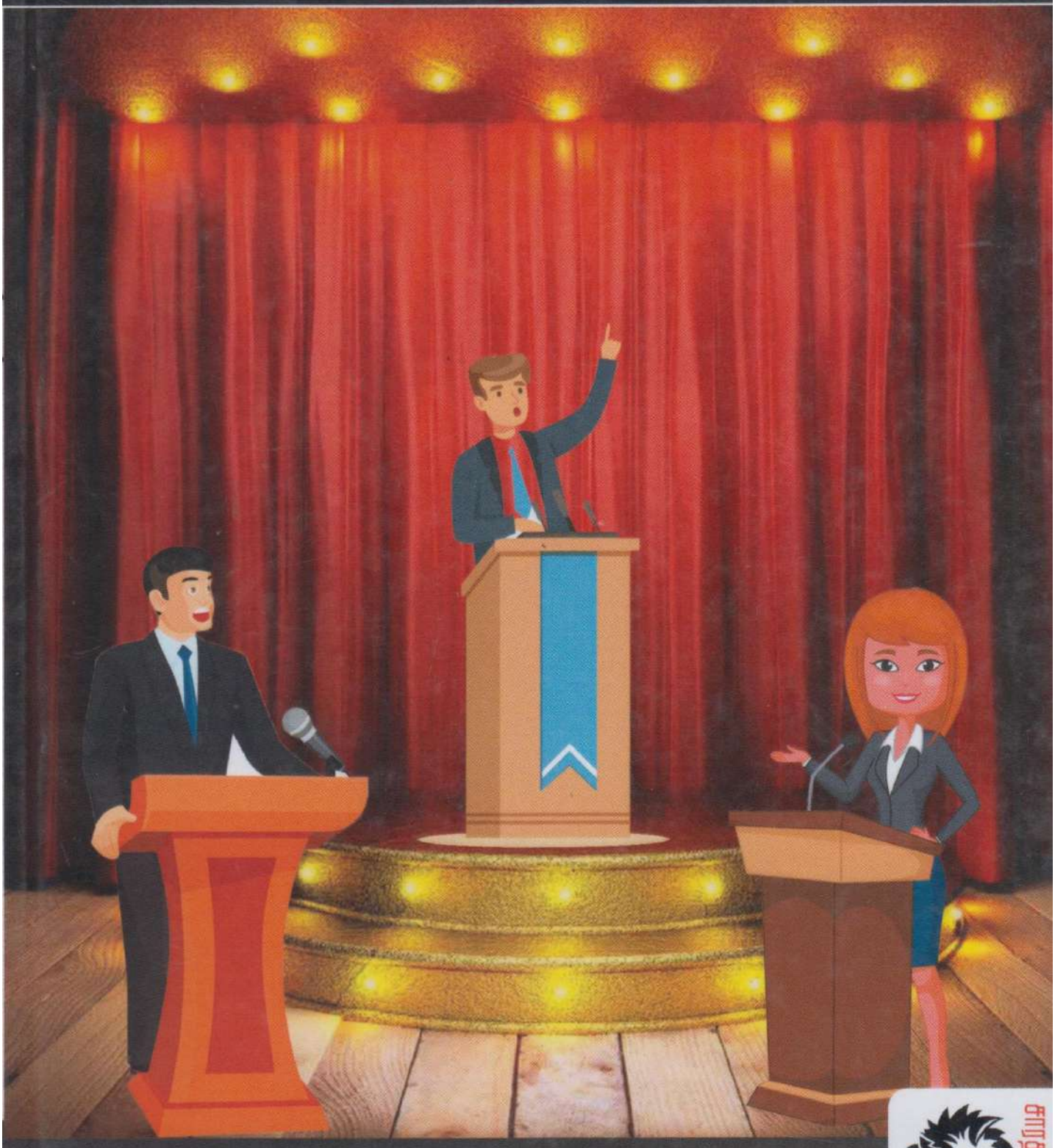
ISBN 978-93-87354-16-6

9 789387 354166

Jami Publications
No.6, Race Course Road
Khajamalai, Tiruchirappalli - 23
Tamil Nadu, India
Mobile : 0 95972 25518
Email : jamitrichy@gmail.com

Print @ The Printing House, Try-23.Ph : 2420121

பேச்சுக்கலை



முனைவர் **ச. ஈஸ்வரன்**

சாரதா பதிப்பகம்

பேச்சுக்கலை

முனைவர் ச. ஈஸ்வரன்
இணைப்போராசிரியர் & தலைவர்,
தமிழ்த்துறை,
தேசியக்கல்லூரி (தன்னாட்சி)
திருச்சிராப்பள்ளி - 620 001.



சாரதா பதிப்பகம், சென்னை-14.
☎ 044 2811 4402 / 044 2844 3791 / 97907 06548

நூல் கிடைக்குமிடம் :

கௌரா புத்தக மையம்
9, செயின்ட் ஜான் சர்ச்சு வணிக வளாகம், ராக்கின்ஸ் சாலை,
திருச்சி - 620 001.
9952034876 / 9943428994
04312419584.

GOWRA PUTHAGA MAIYAM
9, SAINT JOHN CHURCH COMPLEX,
ROCKINS ROAD, TRICHY - 620 001
99520 34876 / 04312419584.
gowraputhagamaiyam@gmail.com

AVAILABLE @ :

கௌரா ஏஜென்ஸீஸ்
எண்.1 சாமி பிள்ளை தெரு,
(சாய் பாபா கோவில் பின்புறம்)
திருவல்லிக்கேணி, சென்னை - 05.
9790706548 / 9790706549
044 28443791.

GOWRA AGENCIES
NO : 1 SAMY STREET,
(SAI BABA TEMPLE BACK SIDE)
TRIPLICANE, CHENNAI - 600005.
9790706548 / 044 28443791.
gowra09@gmail.com

பேச்சுக்கலை - PECHU KALAI

விலை : ரூ. **70.00** CODE : **2121**

எழுதியவர் :
முனைவர் ச. ஈஸ்வரன்
பொருள் : ஆய்வு
© உரிமை : பதிப்பகத்திற்கே
பதிப்பாசிரியர் :
எஸ். கௌமாரீஸ்வரி M.A., M.L.I.S.,
பதிப்பு :
முதற் பதிப்பு – 2020/11
வெளியீடு :
சாரதா பதிப்பகம்
ஜி–4, சாந்தி அடுக்ககம்,
3, ஸ்ரீ கிருஷ்ணாபுரம் தெரு,
ராயப்பேட்டை, சென்னை – 600 014.
பக்கம் : 72
ஒளி அச்சு : ஜெய் ஜீனா
அச்சிட்டோர் :
மீரா ஆப்செட், சென்னை–05.
ISBN :

AUTHOR :
DR S. EESWARAN
SUBJECT : RESEARCH
© RIGHTS : PUBLICATION
PUBLISHER :
S.GOWMAREESWARI M.A., M.L.I.S.,
EDITION :
1ST EDITION - 2020/11
PUBLISHED @ :
SARATHA PATHIPPAGAM
G-4 SHANTHI APARTMENTS,
#3 SRI KRISHNA PURAM STREET,
ROYAPETTAH, CHENNAI - 600 014.
PAGES : 72
TYPESET BY : JAIJEENA
PRINTED @ :
MEERA OFFSET, CHENNAI - 05.
ISBN :

பேச்சுக்கலை



முனைவர் சு. ஈஸ்வரன்

ஆசிரியரின் பிற நூல்கள்

- ★ தமிழ் இலக்கியங்களில் மனித உரிமை சிந்தனைகள் ஓர் அறிமுகம்
- ★ தகவல் தொடர்புகளும் நெறிமுறைகளும்
- ★ சுற்றுலாவியல் ஓர் அறிமுகம்
- ★ இலக்கியக் கொள்கைகள்
- ★ இதழியல் ஓர் அறிமுகம்
- ★ மொழிபெயர்ப்புக் கலை
- ★ இலக்கியத் திறனாய்வு
- ★ ஆய்வும் ஆய்வேடும்
- ★ இலக்கியத் தேடல்
- ★ அறிவியல் தமிழ்

நூல் கிடைக்குமிடம் :

கௌரா புத்தக மையம்
9, செ. ஜான் சர்ச் வணிக வளாகம்,
ராக்கின்ஸ் சாலை, திருச்சி - 1.
gowraputhagamaiyam@gmail.com

கௌரா ஏஜென்ஸீஸ்
1, சாமி தெரு, (சாய் பாபா கோவில் பின்புறம்)
திருவல்லிக்கேணி, சென்னை - 5.
gowra09@gmail.com.
www.facebook.com/gowrabookcentre

கௌரா
பதிப்பக குழுமம்

அட்டை : ஜே.ஜே டிசைன்ஸ்

GO 2121
செப்டம்பர் 2020
ரூ. 70

Estd. 1919

பன்னாட்டுக் கருத்தரங்கம்
தமிழ்ச் சமூகத்தில் வழிபாட்டு மரபுகள்

International Conference on
Worship Culture in Tamil society

நாள்: 28.12.2022

ஆய்வுச்சுருக்கத் தொகுப்பு நூல்

ஆசிரியர்

முனைவர் க. புவனேஸ்வரி,
தமிழாய்வுத்துறை, தேசியக் கல்லூரி (தன்னாட்சி),
திருச்சிராப்பள்ளி–620001, தமிழ்நாடு, இந்தியா

TAMIL AIVU KALANJIYAM

தமிழ் ஆய்வு களஞ்சியம்

9 789393 522245

பன்னாட்டுக் கருத்தரங்கம்

தமிழ்ச் சமூகத்தில் வழிபாட்டு மரபுகள்

நாள்: 28-12-2022

ஆய்வுச்சுருக்கத் தொகுப்பு நூல்

தமிழாய்வுத்துறை,

தேசியக் கல்லூரி (தன்னாட்சி),

திருச்சிராப்பள்ளி–620001, தமிழ்நாடு, இந்தியா,

ISBN: 9789393522245

தமிழ் ஆய்வு களஞ்சியம்

5/11, பெருமாள் கோவில் வீதி, நாயக்கன்பாளையம், கோயம்புத்தூர்641020, இந்தியா

ஆசிரியர்

முனைவர் க. புவனேஸ்வரி
தமிழாய்வுத்துறை, தேசியக் கல்லூரி (தன்னாட்சி), திருச்சிராப்பள்ளி–620001, தமிழ்நாடு, இந்தியா.



ISBN 9789393522245

© Editor's & Author's. This book is an open access publication. Open Access This book is licensed under the terms of the Creative Commons Attribution 4.0 International License (http://creativecommons.org/licenses/by/4.0/), which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

This Tamil Aivu Kalanjiyam imprint is published by the registered company IOR PRESS. The registered company address is: 5/11, Perumal Kovil Street, Naickenpalayam, Coimbatore-641020, Tamil Nadu, India.

வ.எண்	கட்டுரைகள்	ப.எண்
1	தமிழச்சமூகத்தில் வழிபாட்டு மரபுகள் *சி. அமுதா*	1
2	சங்க இலக்கியத்தில் சமூகம், சமுதாயம் மற்றும் சமயம் *அ. முரளி*	2
3	கிறிஸ்தாயனம் வெளிப்படுத்தும் விழாக்கள் *ரா. சுஜிதா*	3
4	கிராம தேவதையும் எல்லை தெய்வமும் *மா. ரெத்தினேஸ்வரி, ம. விமலாராணி*	4
5	மாரியம்மன் வழிபாட்டு மரபும் நம்பிக்கை முறைகளும் *த. தினேஷ்*	5
6	திருவாசகத்தில் வழிபாட்டு மரபுகள் *க. புவனேஸ்வரி, க. விஜயலெட்சுமி*	6
7	வேல ராமமூர்த்தி புதினங்களில் தெய்வங்களும் வழிபாட்டு மரபுகளும் *அ. நந்தினி, பா. சிவன்பாண்டி*	7
8	உடையார் நாவலில் வழிபாட்டு முறைகள் *பா. அன்னிபெசன்ட், க. ஜெயஷீலா*	8
9	புறநானூற்றில் நடுகல் வழிபாடு *இரா. ஜெய்சங்கர்*	9
10	தமிழகத்தில் வழிபாட்டு மரபுகளும் பெண் தெய்வங்களின் தாக்கமும் *க. ஹரிநாத், தி. பார்த்திபன்*	10
11	இறை வழிபாட்டில், 'உறியடி' பெறுமிடம் *ச. ஈஸ்வரன்*	11
12	தமிழ்ச் சமூகத்தில் வழிபாட்டு மரபுகள் (இஸ்லாம் ஓர் சிறப்புப் பார்வை) *ப. மெஹருன்னிசா*	12
13	சங்ககாலம் முதல் தமிழர் விழாக்கள் *க. சுரேஷ்*	13
14	ஜெயமோகன் படைப்புகளில் சிறுதெய்வ வழிபாட்டு மரபுகள் *பா. நாகஜோதி*	14
15	புறநானூற்றில் நடுகல் வழிபாடு *செ. தாமரைச்செல்வி, ச. மல்லிகா*	15
16	சங்க அகநூல்களில் தமிழரின் வழிபாட்டு மரபு *ச. புனிதா*	16
17	தருமபுரி மாவட்டப் போயரின மக்களின் வழிபாட்டு மரபுகள் *வெ. சதீஸ், ரா. தேவணன்*	17

திருவாசகத்தில் வழிபாட்டு மரபுகள்

க. புவனேஸ்வரி [அ, *], க. விஜயலெட்சுமி [அ]

[அ] தமிழ்த்துறை, தேசியக்கல்லூரி (தன்னாட்சி), திருச்சிராப்பள்ளி-620 001, தமிழ்நாடு, இந்தியா.

மின்னஞ்சல் முகவரி: kanapathiviji@gmail.com

ஆய்வுச் சுருக்கம்:

"திருவாசகத்தில் வழிபாட்டு மரபுகள்" என்ற இக்கட்டுரையில் பன்னிரு திருமுறைகளுள் எட்டாம் திருமுறையான திருவாசகத்தில் இறைநெறி மூலம் வழிபாட்டு முறைகள் எடுத்துரைக்கப்பெற்றுள்ளன. சைவ சமயம் என்பது மிகத் தொன்மை வாய்ந்த சமயம் ஆகும். சைவ சமயக்குரவருள் திருஞானசம்பந்தர், திருநாவுக்கரசர், சுந்தரர், மாணிக்கவாசகர் இவர்கள் நால்வரும் சைவக்குரவர்கள் என்று அழைக்கப்படுகின்றனர். இந்நால்வரால் தான் சைவ சமயம் தழைத்தோங்கியது. இந்நால்வரில் சன்மார்க்க நெறியில் இறைவனை வழிபாடு செய்தவர் மாணிக்கவாசகர். சிவபெருமானை நோக்கிச் செய்யும் சரியை, கிரியை, யோகம், ஞானம் என்ற இறை வழிபாட்டுத் தொண்டு முறைகளும் எடுத்துரைக்கப்பட்டுள்ளன. பக்தி நெறியின் வாயிலாகக் கருணை, அன்பின் உருக்கம், மனிதநேயம், இரக்கம், மெய்யுணர்வு நிலையில் பல படிநிலைகளின் தன்மையும் விளக்கப்பெற்றுள்ளன. சன்மார்க்க நெறி தோன்றுவதற்கு அடிப்படைக் காரணமாக இருந்தவர் மாணிக்கவாசகர் அதற்கு அடுத்தபடியாக அதை மக்களிடம் கொண்டு சேர்த்தவர் வள்ளலார், மற்றும் பாரதியார் என்று கூறலாம். இறைவழிபாட்டு முறைகளுள் இது மிகவும் உயர்ந்த உன்னத மார்க்கமாகும். இறைவனோடு இரண்டறக் கலக்கும் பேறு மாணிக்கவாசகருக்கு முன்னும் அவருக்கு பின்னும் யாருக்கும் கிட்டவில்லை. அவர் நிறைவில் இறைவனோடு இரண்டறக்கலந்த தன்மையும் இக்கட்டுரையில் விளக்கப்பெற்றுள்ளது.

"புதுமைப் புனைதல்"

(இலக்கிய மற்றும் சமூகக் கட்டுரைகள்)







முனைவர் க. புவனேஸ்வரி M.A.,M.Phil.,Ph.D.,

நூலின் பெயர்	புதுமைப் புதையல்
ஆசிரியர்	முனைவர் க. புவனேஸ்வரி
பொருள்	இலக்கிய ஆய்வுக் கட்டுரைகள்
மொழி	தமிழ்
உரிமை	ஆசிரியருக்கு
பதிப்பு	ஜூலை 2021
அளவு	தெம்மி
பக்கம்	(iv) + 96 = 100
வெளியீடு	ஜாஸிம் பப்ளிகேஷன்ஸ் காஜாமலை, திருச்சி-23.
நூலாக்கம்	தி பிரிண்டிங் ஹவுஸ், காஜாமலை, திருச்சி-620 023 அலைபேசி : 94435 87233
விலை	ரூ. 100/-
ISBN	978-93-91563-12-7



முனைவர்

க. புவனேஸ்வரி M.A., M.Phil., Ph.D.,

இவர் திருச்சிராப்பள்ளியில் நூற்றாண்டுகளைக் கடந்து வெற்றி நடைபோட்டுக் கொண்டிருக்கும் "தேசியக்கல்லூரி"யின் தமிழாய்வுத் துறையில் உதவிப்பேராசிரியராகப் பணியாற்றி வருகிறார்.

தமிழ், ஆங்கிலம், இந்தி என மும்மொழிப் புலமை மிக்கவர். பேச்சாளர், நிகழ்ச்சித் தொகுப்பாளர், எழுத்தாளர் எனப் பன்முகம் கொண்டவர். 500க்கும் மேற்பட்ட பட்டிமன்றங்களிலும் அகில இந்திய வானொலியின் பல்வேறு நிகழ்ச்சிகளிலும் உரையாற்றியுள்ளார். கலைஞர் தொலைக்காட்சியின் "விடியலே வா" எனும் நிகழ்ச்சியில் சிறப்பு விருந்தினராகப் பங்கேற்றுப் பேட்டி அளித்துள்ளார்.

"இலக்கியச்சுடர்", "மனிதநேய கவிச்செம்மல்", "இக்கால பாரதி" போன்ற விருதுகளைப் பெற்றவர்.

"மு. மேத்தாவின் முப்பரிமாணம்" என்ற இவரது முதல் நூலில் கவிஞர். மு. மேத்தாவின் சமுதாயச் சிந்தனைகள் பற்றியும், "மாண்புறு மங்கையர்" என்ற நூலில் கம்பராமாயணத்தில் பெண்களின் நிலை பற்றியும் எழுதியுள்ளார்.

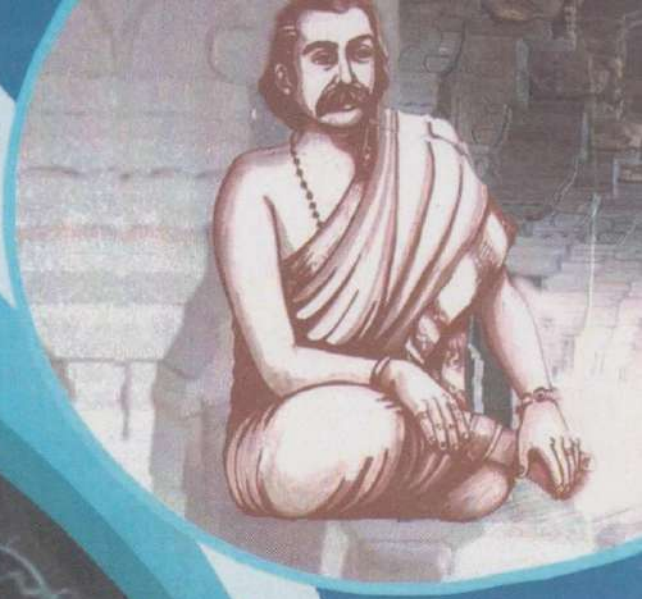
"புதுமைப் புதையல்" எனும் இந்நூல் தமிழ் இலக்கியத்தின் பல்வேறு தளங்களில் இவர் நிகழ்த்திய ஆய்வுகளின் தொகுப்பாக வெளிவருகிறது.

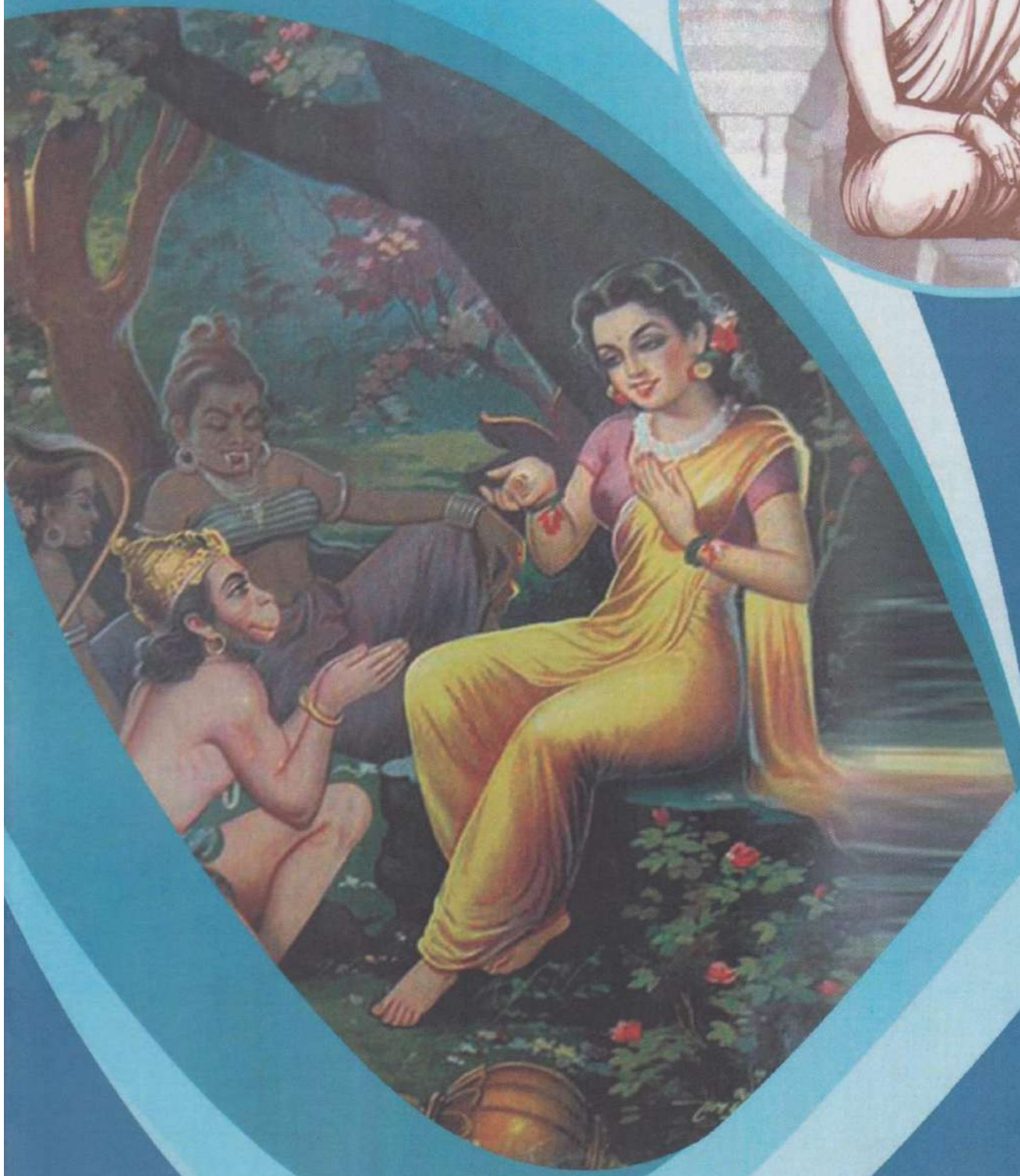
ISBN 978-93-91563-12-7

PJAZYM PUBLICATIONS
No.1, Post Office Street
Khajamalai, Trichy - 23

9 789391 563127

Print @ The Printing House, Try-23. Ph:0431-2420121





மான்புறு மங்கையர்

முனைவர் க. புவனேஸ்வரி M.A.,M.Phil.,Ph.D.,

Title of the Book	:	Maanburu Mangaiyar
ISBN No.	:	978-93-5291-305-3
Genre	:	Literature - Research
Author	:	© K. BHUVANESWARI
Copyright	:	To Author
First Edition	:	December, 2017
Price	:	Rs. 150/-
Total No. of Pages	:	160
Size	:	Demmy (1/8)
Wrapper Design	:	Jeyam Offset Printers, PUDUKKOTTAI - 622001.
Printed at	:	Real Impact, Mylapore, CHENNAI - 600004.
Published by	:	Muthu Bhuvana Pathippagam, 49/46, North Car Street, T.V. Kovil, TRICHY - 600005. Ph: 99401 14755



முனைவர்

க. புவனேஸ்வரி M.A.,M.Phil.,Ph.D.,

கவிஞர். நா. கண்ணன் - திருமதி. இரா. விஜயலெஷ்மி என்னும் ஆசிரியத் தம்பதியரின் அருமை மகளாக, 1978 - ல், புதுக்கோட்டையில் பிறந்தவர். இளங்கலை தமிழ் இலக்கியத்தில், பல்கலைக் கழக அளவில் முதல் மாணவியாகத் தேர்ச்சி பெற்றவர். தொடர்ந்து முதுகலை, ஆய்வியல் நிறைஞர் மற்றும் முனைவர் பட்டங்களையும் தமிழ் இலக்கியத்திலேயே பெற்றார். கல்லூரி விரிவுரையாளருக்கான SLET & NET தேர்வுகளிலும் தேர்ச்சி பெற்றுள்ளார்.

தற்போது, திருச்சிராப்பள்ளியில் உள்ள தேசியக் கல்லூரியின் தமிழ்த்துறையில், உதவிப் பேராசிரியராகப் பணியாற்றி வருகிறார். M.Phil., Ph.D., போன்ற ஆய்வுப் பட்டங்களுக்கு வழிகாட்டும் ஆய்வு நெறியாளராகவும் உள்ளார்.

பள்ளி நாட்களிலேயே பல்வேறு பேச்சுப்போட்டிகளில் பங்கேற்று பரிசுகளைக் குவித்த இவர், முதுகலை பயிலும் போதே முன்னணி மேடைப் பேச்சாளராக வலம் வந்தவர். திருமதி. சரஸ்வதி ராமநாதன், திரு. சோ. சத்தியசீலன், திரு. அ. அறிவொளி, திரு. சாலமன் பாப்பையா, திரு. சுகி. சிவம், திரு. ப. நமச்சிவாயம் போன்ற தலைசிறந்த பேச்சாளர்களின் தலைமையில், 500-க்கும் மேற்பட்ட பட்டிமன்றங்களில் பேசியுள்ளார்.

இவரின் எழுத்துக்கள் 'வளம்பெற யோசி', 'நாளைய இந்தியா' போன்ற பல இதழ்களில் வெளிவந்துள்ளன. தமிழ், ஆங்கிலம், இந்தி என மும்மொழிகளிலும் புலமை மிக்கவர். அகில இந்திய வானொலியில் பல்வேறு நிகழ்ச்சிகளில் உரையாற்றியுள்ளார். கலைஞர் தொலைக் காட்சியின் 'விடியலே வா' என்ற நிகழ்ச்சியில் சிறப்பு விருந்தினராகப் பேட்டி அளித்துள்ளார்.

இவரின் கணவர் திரு. வெ. முத்துகிருஷ்ணன், தனியார் நிறுவனத்தில் பணியாற்றி வருகிறார். இவர்களுக்கு செல்வி காமாட்சி, செல்வன் ஆதித்யா என இரு குழந்தைகள் உள்ளனர்.

ISBN 978-93-5291-305-3



₹. 150/-

முத்து புவனா பதிப்பகம்

வாழும் வள்ளுவம்

(ஆய்வுக் கட்டுரைத் தொகுப்பு)



தொகுப்பாசிரியர்

உடையார்கோயில் குணா

பதிப்பாசிரியர்கள்

முனைவர் ஆ. முருகானந்தம்

முனைவர் க. மணிமேகலை

முனைவர் மு. சுபாஷினி

முனைவர் பொன். இரமேஷ்குமார்

பேராசிரியர் அ. அம்பேத்கர்

ஆசிரியை கு.செ. சரஸ்வதி

உலகத் திருக்குறள் மூன்றாவது மாநாடு-2021



தமிழ்த்தாய் அறக்கட்டளை வெளியீடு - 32

நூல் குறிப்பு

தலைப்பு	வாழும் வள்ளுவம் (ஆய்வுக் கட்டுரைத் தொகுப்பு)
தொகுப்பாசிரியர்	உடையார்கோயில் குணா
பதிப்பாசிரியர்கள்	முனைவர் ஆ. முருகானந்தம் முனைவர் க. மணிமேகலை முனைவர் மு. சுபாஷினி முனைவர் பொன். இரமேஷ்குமார் பேராசிரியர் அ. அம்பேத்கர் ஆசிரியை கு.செ. சரஸ்வதி
முதல் பதிப்பு	பிப்ரவரி 2021
தொகுதி	7
மொழி	தமிழ்
உரிமை	தமிழ்த்தாய் அறக்கட்டளை
அளவு	டெம்மி
பக்கம்	248
கணினி அச்சு	கனிஷ்கி கிராபிக், மதுரை. 9677937794
அட்டை வடிவமைப்பு	ஆ.சு. கண்ணன், மதுரை
அச்சாக்கம்	மாணவர் நகலகம், சென்னை.
வெளியீடு	தமிழ்த்தாய் அறக்கட்டளை, மாரியம்மன்கோயில், தஞ்சாவூர் - 613 501. தமிழ்நாடு. இந்தியா.
பேச	0091 75300 02454, 94439 38797
மின்னஞ்சல்	thamilthaitrust@gmail.com
விலை	ரூ. 250/-
ISBN	978-81-909877-6-9



முனைவர் கோ.விசயராகவன்

இயக்குநர்,
தமிழ் வளர்ச்சித் துறை மற்றும்
உலகத் தமிழாராய்ச்சி நிறுவனம்
தமிழ்நாடு அரசு, சென்னை.

உலக இலக்கியமான திருக்குறளை, தமிழ்தாய் பெற்றதால் தலைநிமிர்ந்து விளங்குகிறாள். தமிழ் கூறும் நல்லுலகான தமிழ்நாடும், தலைநிமிர்ந்து உள்ளது. உலகத் தமிழர்கள் பெருமை கொள்கிறார்கள்.

தமிழர்கள் அனைவரும் உலக இலக்கியமான திருக்குறளை கற்க வேண்டியது கடப்பாடு ஆகும். இன்றைய நாளில் குறளின் கருத்துகள் உலகம் முழுவதும் பரவுவதற்கானச் சூழல்கள் உருவாகியுள்ளன. தமிழ்நாடு அரசு முதலிடத்தில் நின்று, திருக்குறளை பரவச் செய்வதில் முனைப்பு காட்டி வருகிறது.

அரசு சாராமல் தன்னார்வத் தமிழ் அமைப்பின் பலரும் திருக்குறள் பரப்பும் பணிகளை உலகமெங்கும் செய்து வருகிறார்கள். அந்த வகையில் தஞ்சாவூர், தமிழ்த்தாய் அறக்கட்டளை சார்பாக, திருக்குறள் மாநாடு நடத்துவதும், திருவள்ளுவர் சிலைகளை உலகெங்கும் அன்பளிப்பாக வழங்கி, நிறுவுவதும் பாராட்டத்தக்க முயற்சி ஆகும்.

முதலாவது மாநாட்டின் வாயிலாக மலேசியா, பினாங்கு இந்திய கலாசார மையத்திலும், இரண்டாவது மாநாட்டின் வாயிலாக இலங்கை யாழ்ப்பாணம் உரும்பிராய் நகரிலும், காரைத்தீவு நகரிலும் இரண்டு திருவள்ளுவர்

பொருளடக்கம்

1. திருக்குறள் காட்டும் புரட்சி சிந்தனைகள் 15
முனைவர் ஆ முருகானந்தம்

2. வள்ளுவர் கூறும் நட்பு 24
முனைவர் க.மணிமேகலை,

3. வள்ளுவர் சுட்டும் தீமைகள் 32
முனைவர் தமிழரசி கோதை மார்பன்

4. வள்ளுவர் காட்டிய வழியில் தி.வெ.ராவின் படைப்புகள் 39
திருமதி ப. கௌரி

5. திருக்குறளில் பெற்றோர் குழந்தைகள் உறவுகள் 41
திருமதி கு.செ.சரஸ்வதி

6. திருக்குறளில் காணும் சமூக சீர்திருத்த சிந்தனைகள் 50
பா. மதிவாணன்

7. திருக்குறளில் மீளிணக்கம் 58
துரை. வைரமணி

8. திருக்குறளிள் படர்ந்துள்ள உவமைகள் 64
முனைவர். சி. அருள் செல்வம்,

9. திருக்குறள் போற்றும் நட்பு 78
அ.சேதுபதி

10. தமிழ் மறையின் சிறப்பு 84
கவிஞர்.மு.க.பரமசிவம்

11. திருக்குறளில் தீதும் நன்றும் 93
தை. அந்தோணி ராஜ்



முனைவர் கோ.விசயராகவன்

இயக்குநர்,
தமிழ் வளர்ச்சித் துறை மற்றும்
உலகத் தமிழாராய்ச்சி நிறுவனம்
தமிழ்நாடு அரசு, சென்னை.

உலகத் தமிழாராய்ச்சி நிறுவனமும், ஆஸ்திரேலிய மெல்பர்ன் தமிழ்ச் சங்கமும், இளங்காடு நற்றமிழ்ச் சங்கமும், தஞ்சாவூர் தமிழ்த்தாய் அறக்கட்டளையும் இணைந்து உலகத் திருக்குறள் மூன்றாவது மாநாட்டை தஞ்சாவூர், பாரத் அறிவியல் நிர்வாகவியல் கல்லூரியிலும், நாவலர் ந.மு. வேங்கடசாமி நாட்டார் திருவருள் கல்லூரியிலும் 2021 பிப்ரவரி 26, 27, 28 இல் நடத்த இருப்பது வரலாற்று சிறப்பு மிக்க முயற்சியாகும்.

தஞ்சாவூர், தமிழ்த்தாய் அறக்கட்டளையின் பொதுச் செயலாளர் கவிஞர் உடையார்கோயில் குணா எடுத்துக் கொண்ட முயற்சியின் பலனாக, சென்னையில் கடந்த 17.03.2013 திருக்குறள் தேசிய நூல் கோரிக்கை மாநாடு, அரசு அருங்காட்சியகத்தில் நடைபெற்றது.

அதனைத் தொடர்ந்து, திருக்குறளை உலகப் பொதுமறையாக UNESCO நிறுவனம் அறிவிக்க வேண்டும் என கோரிக்கை விடுத்து, 2019ஆம் ஆண்டு பிப்ரவரியில் மலேசியாவில் உலகத் திருக்குறள் முதலாவது மாநாட்டையும், 2020ஆம் ஆண்டு பிப்ரவரியில் இலங்கை யாழ்ப்பாணத்தில் உலகத் திருக்குறள் இரண்டாவது மாநாட்டையும் வெற்றிகரமாக நடத்தி முடித்து, தற்போது தஞ்சாவூரில் உலகத் திருக்குறள் மூன்றாவது மாநாடு நடைபெற இருப்பது பாராட்டுக்குரியது.

உலகத் தமிழ் மாநாட்டை தமிழ்நாடு அரசு முன்னெடுத்து உலகெங்கும் நடத்தி, மகிழ்வதைப் போன்று, இனி உலகத் திருக்குறள் மாநாட்டையும் தொடர்ந்து உலகெங்கும் நடத்த இது ஒரு சிறந்த முயற்சியாகும்.

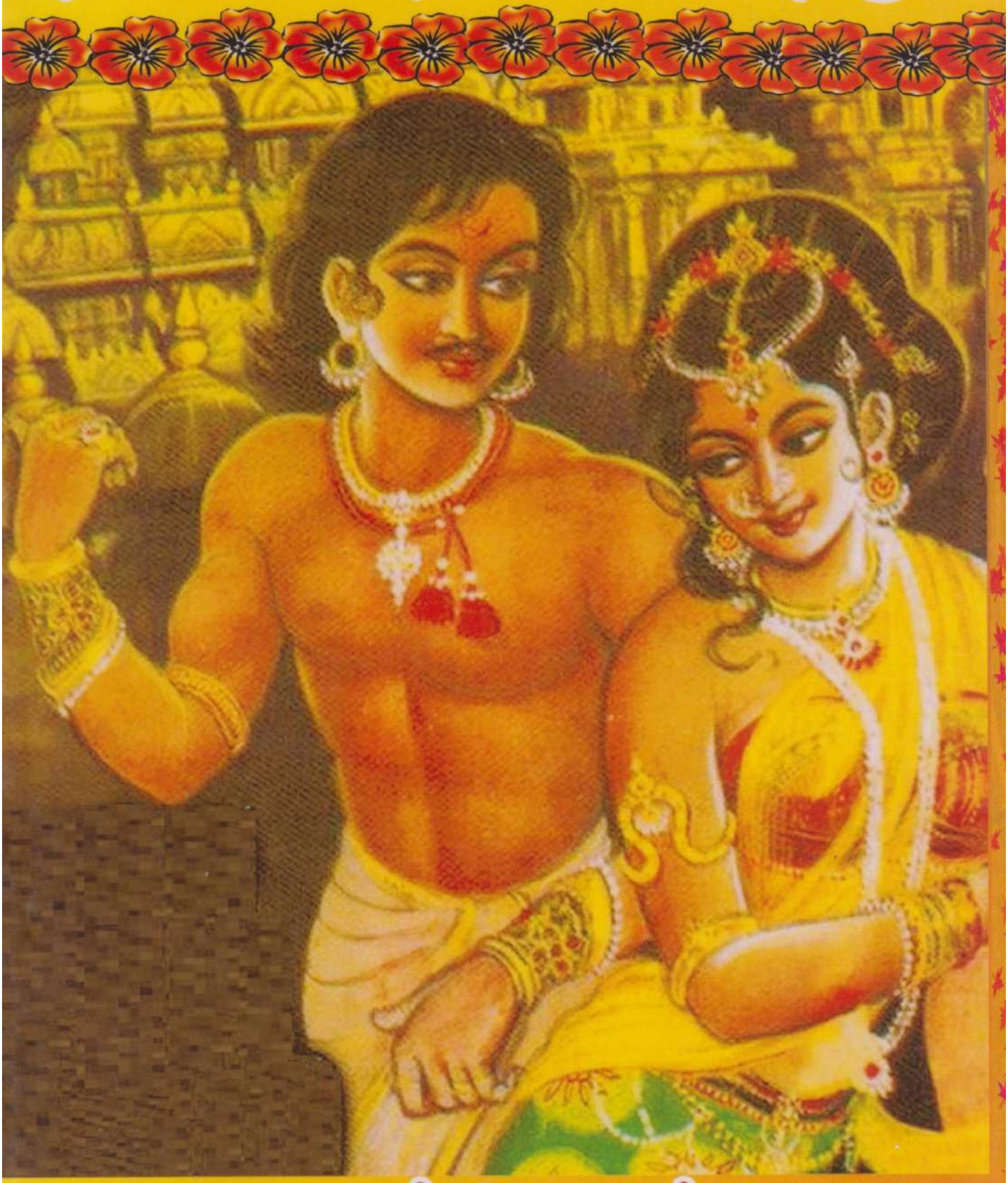
உள்ளத்தனையது உயர்வு

விலை : ரூ.250/-

ISBN : 978-81-909877-6-9

9 788190 987769

சங்க அக இலக்கியங்களில் தலைவன் தலைவி கூற்று



முனைவர் இரா. பத்மா

நூல் அமைப்பு

நூலின் பெயர்	:	சங்க அக இலக்கியங்களில் தலைவன் தலைவி கூற்று
ஆசிரியர்	:	முனைவர் இரா. பத்மா
பொருள்	:	ஆய்வு
பதிப்பு	:	டிசம்பர் 2021
நூலின் அளவு	:	டெம்மி
பக்கம்	:	137
விலை	:	150 /-
அச்சிட்டோர்	:	யூனிவர்சல் அச்சகம் இராயப்பேட்டை, சென்னை-600 014
ISBN	:	978 - 93 - 94743 - 13 - 7

அணிந்துரை

சங்க அக இலக்கியங்களில் தலைவன், தலைவி கூற்றுகள் என்னும் இந்நூலினை முனைவர் இரா. பத்மா அவர்கள் சிறந்த முறையில் படைத்துள்ளார்கள்.

சங்க கால தமிழர்களின் அகவாழ்வினை ஆராயும் வகையில் சங்க அக இலக்கியங்களில் கூற்றுகள் என்னும் தலைப்பில் இந்நூலில் பல செய்திகள் இடம் பெறுகின்றன. தலைவனின் சிறப்பு, வீரம், பண்பு ஆகியவை தலைவன் கூற்றில் சிறப்பான முறையில் கூறப்பட்டுள்ளது. தலைவன் ஒழுக்கம் இயற்கைப் புணர்ச்சி, கற்பொழுக்கம், பிரிவுத் துயரம் போன்ற செய்திகள் சிறந்த முறையில் வெளிக்காட்டப்பட்டுள்ளது. களவு கூற்று, கற்புக் கூற்று என கூற்றுகளை கூறிய விதம் மிகவும் அருமை. தமிழ் மக்களின் அகவாழ்வினை ஆராய்வதோடு பண்டையச் சமுதாயத்தின் கலாச்சார, பண்பாட்டு முறைகளையும் இந்நூல் வெளிக்காட்டுகிறது. அக இலக்கிய கூற்றுக்களை முழுமையாக உணர இந்நூல் உறுதுணை புரியும். முனைவர் இரா. பத்மா அவர்கள் பல நூல்களை படைத்து தமிழ் இலக்கியத்திற்குச் சிறப்பு செய்திட மனதார வாழ்த்துகிறேன்.

முனைவர் ராதிகா மேகநாதன்
ஊதவிப் பேராசிரியர், தமிழ்த்துறை
பி.எஸ். அப்துர் ரஹ்மான் கிரசண்ட் அறிவியல் மற்றும்
தொழில் நுட்பக் கல்வி நிறுவனம்
வண்டலூர், சென்னை - 600 048.

பொருளடக்கம்

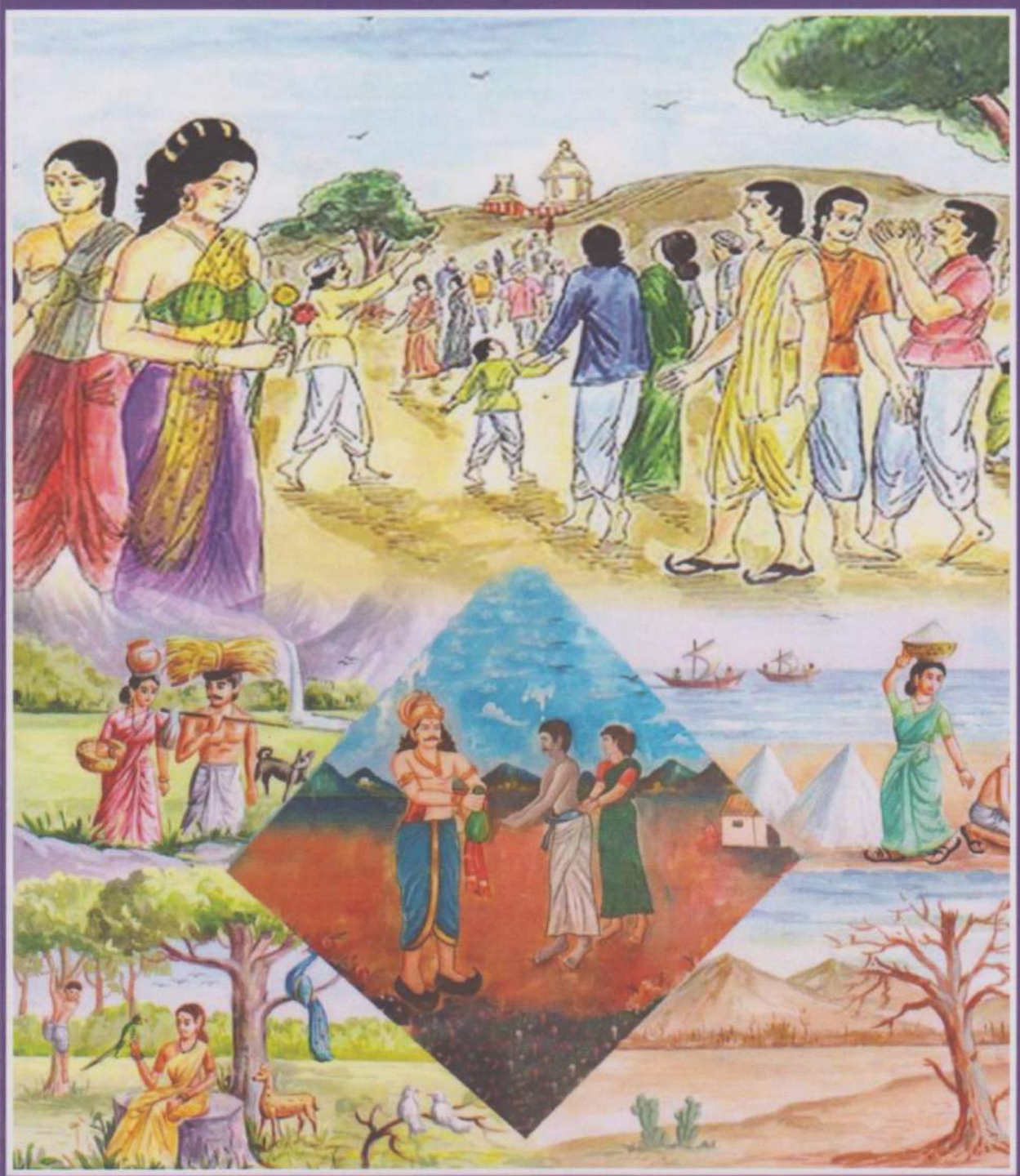
முன்னுரை	-	7
தலைவன் கூற்று	-	14
தலைவி கூற்று	-	52
முடிவுரை	-	97
அகப்பாடல்களில் அகமாந்தர்களின் கூற்றுகள் பின்னிணைப்பு	-	100
துணை நூற்பட்டியல்	-	126

சுருக்கக் குறியீட்டு விளக்கம்

1. அகம்	-	அகநானூறு
2. உ. ஆ.	-	உரையாசிரியர்
3. உ.வே.சா	-	உ.வே. சாமிநாதஐயர்
4. ஐங்	-	ஐங்குறுநூறு
5. கலி	-	கலித்தொகை
6. குறள்	-	திருக்குறள்
7. குறு	-	குறுந்தொகை
8. சை. சி. நூ.கழகம்	-	சைவ சித்தாந்த நூற்பதிப்புக்கழகம்
9. தொல்	-	தொல்காப்பியம்
10. தொல், களவு	-	தொல்காப்பியம், களவியல்
11. தொல், கற்பு	-	தொல்காப்பியம், கற்பியல்
12. தொல், பொருள்	-	தொல்காப்பியம், பொருளதிகாரம்
13. நற்	-	நற்றிணை
14. நூ.	-	நூற்பா
15. ப.	-	பக்கம்.
16. பா.	-	பாடல்கள்
17. ப.ஆ	-	பதிப்பாசிரியர்
18. மேலது	-	மேலே குறிப்பிட்ட நூல்



ஆற்றுப்படை நூல்களில் சுற்றுச்சூழல் சிந்தனைகள்



முனைவர் மு. சுபாஷினி

ஆற்றுப்படை நூல்களில் சுற்றுச்சூழல் சிந்தனைகள்

முனைவர் மு.சுபாஷினி

முதற்பதிப்பு : ஜூன் 2022

வெளியீடு : பரிதி பதிப்பகம்
56சி/128. பாரத கோயில் அருகில், ஜோலார்பேட்டை,
திருப்பத்தூர் மாவட்டம் - 635 851
மின்னஞ்சல் : Parithijpt@gmail.com

அச்சாக்கம் : மணி ஆப்செட், சென்னை
ஒளி அச்சு : தங்கம் கிராஃபிக்ஸ்

பக்கங்கள் : 92
விலை: ரூ.100

Attupadai Noolkalil Sutrucholal Sindanaigal

Dr.M.Subashini

First Edition - June 2022

Parithi Pathippagam
Published by Parithi Pathippagam
56C/128, Near Bharatha Kovil, Jolarpettai,
Tirupattur District-635851 Cell: 72006 93200
Email: Parithijpt@gmail.com

Printed at: clictoprint | *Chennai-600 018.*
Layout: Thangam Graphics, Chennai

Pages : 92
Price : Rs. 100

ISBN No : 978-93-94187-65-8

வாழ்த்துரை



டாக்டர் இ.ஆர்.இரவிச்சந்திரன்
முதல்வர்,
உருமு தனலெட்சுமி கல்லூரி
காட்டூர்
திருச்சிராப்பள்ளி - 620019.

மனித வாழ்க்கையில் இலக்கியங்கள் முதன்மையாக விளங்குகின்றன. மனிதனின் நுட்பமான அறிவையும், அனுபவத்தையும், ஆழமான சிந்தனைகளையும் விதைக்கும் வித்தாக அமைந்து விருட்சமாக வளர வைப்பது இலக்கியங்களே என்றால் மிகையல்ல. தமிழ் இலக்கியங்களை ஆராய்ச்சியுடன் நோக்கினால் பற்பல உண்மைகள் தெற்றெனப் புலப்படும்.

சங்க இலக்கியங்களானப் பத்துப்பாட்டில் ஆற்றுப்படை நூல்கள் ஐந்து. அவற்றிலுள்ள செய்திகளை நுணுகிப் பார்த்தால் அறிவியல் சார்ந்த கருத்துகள் ஏராளமாக உள்ளன. இலக்கியங்களை மேலோட்டமாகப் பார்த்தோமேயானால் பண்டைய மக்களின் காதலும், வீரமும் கண்முன் தெரிவதுபோல இருக்கும். நுட்பமான முறையில் ஆராய்ந்தால் இயற்கையைச் சார்ந்து வாழும் மக்கள் சுற்றுச்சூழலை அறிவியல் முறையோடு காத்து வந்தமையை அறியமுடியும்.

ஐம்பெரும்பூதங்களான நிலம், நீர், காற்று, தீ, வானம் ஆகிய இயற்கையின் சேர்க்கையினாலேயே அனைத்து உயிரினங்களும் வாழ்கின்றன. இத்தகைய சிறப்பு வாய்ந்த இயற்கையைத் தூய்மையாக வைத்திருக்கும் உத்தி

பொருளடக்கம்

வ. எண்	தலைப்பு	பக்க எண்
	முகவுரை	11
1	சுற்றுச்சூழல் பொருளாய்வு	11
2	சூழலியலின் தோற்றம்	12
3	நிலம்	21
4	நிலமயக்கம்	34
5	நிலம் மாசுறுதல்	36
6	நீர்	40
7	மழை நீர்	49
8	அருவி நீர்	49
9	ஆற்று நீர்	55
10	குளத்து நீர்	58
11	கடல் நீர்	61
12	நீர் மாசுபாடு	66
13	காற்று	68
14	காற்று மாசுபாடு	75



இந்நூலாசிரியரைப் பற்றி

முனைவர் **மு.சுபாஷினி,**
உதவிப் பேராசிரியர் (நிர்வாக நியமனம்),
தமிழாய்வுத்துறை, தேசியக்கல்லூரி (தன்னாட்சி),
திருச்சிராப்பள்ளி - 01.

முனைவர் மு.சுபாஷினி மணப்பாறை வட்டம் தொப்பம்பட்டி என்னும் கிராமத்தில் பிறந்தவர். போக்குவரத்து வசதி இல்லா ஊரில் இடைநிலைக் கல்விக்குமேல் தொடர்ந்து மேற்படிப்பைப் படித்த முதல் பெண்மணி ஆவார். எம்.ஏ.,பி.எட்., எம்ஃபில்., பிஜிடிசிஏ., பிஎச்.டி., ஆகிய பட்டங்களைப் பெற்றவர்.

முதுகலைப் பயிலும் போதே ஆராய்ச்சிக் கட்டுரை எழுதத் தொடங்கியவர். எண்பதுக்கும் மேற்பட்ட ஆய்வுக் கட்டுரைகளைப் பல்வேறு கல்லூரிகளுக்கு வழங்கியுள்ளார்.

கவியரசர் கலைத் தமிழ்ச் சங்கம் நடத்திய மாநில அளவிலான கட்டுரைப் போட்டியில் "இலக்கியச் சுடர் விருது" (2011), குறிஞ்சிக் கபிலர் தமிழ்ச் சங்கம் நடத்திய மாநில அளவிலான ஓவியப் போட்டியில் "வரைகலை வளர்மணி விருது" (2013), கொங்குநாடு கலை அறிவியல் கல்லூரி, கோவை, கதைத்தமிழ் ஆய்வு மாநாட்டிற்கு ஆய்வுக் கட்டுரை வழங்கியமைக்காகக் "கதை ஆய்வுச்சுடர் விருது" (2015), கவியரசர் கலைத் தமிழ்ச் சங்கம் "பேராசிரியர் ரத்னா விருது" (2018) ஆசிரியர் தின விழாவில் வழங்கியது.

பொருநை இலக்கியக் களம் மற்றும் சான்லாக்ஸ் பன்னாட்டுத் தமிழியல் ஆய்விதழ் நடத்திய பன்னாட்டுக் கருத்தரங்கிற்கு ஆய்வுக் கட்டுரை வழங்கியமைக்காகத் "தமிழ் இலக்கிய வித்தகர் விருது" (2019) பெற்றார். குறிஞ்சிக் கபிலர் தமிழ்ச் சங்கம் சேவைத் தொண்டினைப் பாராட்டி 70வது குடியரசு தின விழாவில் "சாதனைச் செம்மல் விருது" (2019) பெற்றார்.

மாணவர்களை ஊக்கப்படுத்திக் கட்டுரை எழுத வைத்தமையைப் பாராட்டி "சேவா ரத்னா விருது" (2019) கவியரசர் கலைத் தமிழ்ச் சங்கம் வழங்கியது. உலகத் திருக்குறள் மாநாடு மலேசியா பல்கலைக்கழகத்திற்குக் கட்டுரை வழங்கியமைக்குப் "பேராளர் நினைவுப் பரிசு" (2019) பெற்றார். அனைத்திந்திய அறிவியல் தமிழ்க் கழகம் தஞ்சையில் நடத்திய 25 வெள்ளிவிழா கருத்தரங்கிற்கு ஆய்வுக் கட்டுரை வழங்கியமைக்காக "நினைவுப் பேழை" (2019) ஆகிய விருதுகளைப் பெற்றவர்.

அகிலம் போற்றும் ஆசிரியர்கள் எனும் தலைப்பில் வகுப்பறை பள்ளிக் கல்வி இதழுடன் மதுரை காமராசர் பல்கலைக்கழகம் நடத்திய கருத்தரங்கில் சிறந்த கட்டுரை வழங்கியமையைப் பாராட்டி "சிலம்பொலி செல்லப்பனார் விருது" (2019) பெற்றார்.

உலக ஆசிரியர் தினத்தை முன்னிட்டு கல்விப் பணியில் சிறந்து விளங்கியமையைப் பாராட்டி கலை இலக்கிய ஆய்வு மையம், கும்பகோணம் "பேராசிரியர் சிகரம் விருது" (2020) வழங்கியது.

தமிழ்ப்பணியினையும், தனித்திறனையும் பாராட்டி தமிழ்நாடு கலை இலக்கிய கழகம், கொட்டாரம் "தமிழ் ரத்னா விருது" (2020) வழங்கி சிறப்பித்தது.

கல்லூரி மாணவ, மாணவியர்கள் எளிமையாகப் புரிந்து கொள்ளும் வகையில் தொல்காப்பியம் சொல்லதிகாரம் வினா விடை புத்தகம் 2021இல் வெளியிட்டுள்ளார்.

ஆய்வுப்பணியில் சிறந்து விளங்கியமைக்கு மருதம் கலை இலக்கிய ஆய்வு மையம், கும்பகோணம் "ஆய்வாளர் செம்மல் விருது" (2021) வழங்கியது.

பரிதி பதிப்பகம்



ISBN: 978-93-94187-65-8
9 789394 187658
விலை: ₹100

ஆற்றுப்படை நூல்களில் தாவரவியல் சிந்தனைகள்



முனைவர் மு. சுபாஷினி

ஆற்றுப்படை நூல்களில் தாவரவியல் சிந்தனைகள்

முனைவர் மு.சுபாஷினி

முதற்பதிப்பு : ஜூன் 2022

வெளியீடு : பரிதி பதிப்பகம்
56சி/128. பாரத கோயில் அருகில், ஜோலார்பேட்டை,
திருப்பத்தூர் மாவட்டம் - 635 851
மின்னஞ்சல் : Parithijpt@gmail.com

அச்சாக்கம் : மணி ஆப்செட், சென்னை
ஒளி அச்சு : தங்கம் கிராஃபிக்ஸ்

பக்கங்கள் : 108
விலை: ரூ.100

Attupadai Noolkalil Thavaraviyal Sindanaigal

Dr.M.Subashini

First Edition - June 2022

Parithi Pathippagam
Published by Parithi Pathippagam
56C/128, Near Bharatha Kovil, Jolarpettai,
Tirupattur District-635851 Cell: 72006 93200
Email: Parithijpt@gmail.com

Printed at: clictoprint | *Chennai-600 018.*
Layout: Thangam Graphics, Chennai

Pages : 108
Price : Rs. 100

ISBN No : 978-93-94187-66-5

வாழ்த்துரை

முனைவர் **அர.கமலத்தியாகராஜன்**
இணைப்பேராசிரியர் (ப.நி)
அறிவியல் தமிழ் மற்றும் தமிழ் வளர்ச்சித்துறை
தமிழ்ப் பல்கலைக்கழகம்
தஞ்சாவூர்

தமிழ்மொழியின் சிறப்பைத் தலைநிமிர்ந்து வாழவைப்பன இலக்கியங்கள் ஆகும். இலக்கியத்தை ஆராய்ச்சியுடன் நோக்கினால் பல செய்திகளை அறியமுடியும். சங்ககாலப் புலவர்கள் முதல் இக்காலக் கவிஞர்கள் வரை நுண்மான் நுழைபுலத்தால்; கண்டறிந்த நிகழ்வுகளைத் தம் படைப்புகளில் பதிவு செய்துள்ளனர்.

புலவர்கள் தம் அறிவின் திறத்தால் கண்டறிந்த மெய்ம்மைகளை எதிர்காலச் சமுதாயம் உணர வேண்டும் என்பதற்காகப் பாடல்களில் வெளிப்படுத்துகின்றனர். ஆற்றுப்படைப் புலவர்கள் இயற்றிய பாடல்களை முழுமையாக ஆராய்ந்து, அவற்றில் இருக்கும் அறிவியல் கருத்துகளை ஒவ்வொரு பிரிவாகப் பிரித்துக் காட்டியுள்ளமை இந்நூலின் சிறப்பாகும்.

தாவரங்களைப் பற்றிய கருத்துகளை ஆற்றுப்படை நூல்களில் இருந்து எடுத்து விளக்கும் நூலாசிரியர் முனைவர் மு.சுபாஷினி அவர்கள் மரங்கள், செடிகள், கொடிகள், புற்கள், கிழங்குகள், மலர்கள் என்று பிரித்து வகைப்படுத்தி, அவற்றின் இன்றியமையாமையையும் விளக்கிக் கூறியது இந்நூலுக்குச் செம்மை சேர்க்கிறது.

பொருளடக்கம்

வ. எண்	தலைப்பு	பக்க எண்
	முகவுரை	11
1	தாவரவியல்	11
2	புலால் உண்ணும் தாவரங்கள்	13
3	மரங்கள்	14
4	செடிகள்	49
5	கொடிகள்	61
6	புற்கள்	71
7	கிழங்குகள்	79
8	மலர்கள்	84
9	தொகுப்புரை	89
10	சான்றெண் விளக்கம்	92
11	துணைநூற்பட்டியல்	95
12	பின்னிணைப்புகள்	101



இந்நூலாசிரியரைப் பற்றி

முனைவர் **மு.சுபாஷினி,**
உதவிப் பேராசிரியர் (நிர்வாக நியமனம்),
தமிழாய்வுத்துறை, தேசியக்கல்லூரி (தன்னாட்சி),
திருச்சிராப்பள்ளி - 01.

முனைவர் மு.சுபாஷினி மணப்பாறை வட்டம் தொப்பம்பட்டி என்னும் கிராமத்தில் பிறந்தவர். போக்குவரத்து வசதி இல்லா ஊரில் இடைநிலைக் கல்விக்குமேல் தொடர்ந்து மேற்படிப்பைப் படித்த முதல் பெண்மணி ஆவார். எம்.ஏ.,பி.எட்., எம்ஃபில்., பிஜிடிசிஏ., பிஎச்.டி., ஆகிய பட்டங்களைப் பெற்றவர்.

முதுகலைப் பயிலும் போதே ஆராய்ச்சிக் கட்டுரை எழுதத் தொடங்கியவர். எண்பதுக்கும் மேற்பட்ட ஆய்வுக் கட்டுரைகளைப் பல்வேறு கல்லூரிகளுக்கு வழங்கியுள்ளார்.

கவியரசர் கலைத் தமிழ்ச் சங்கம் நடத்திய மாநில அளவிலான கட்டுரைப் போட்டியில் "இலக்கியச் சுடர் விருது" (2011), குறிஞ்சிக் கபிலர் தமிழ்ச் சங்கம் நடத்திய மாநில அளவிலான ஓவியப் போட்டியில் "வரைகலை வளர்மணி விருது" (2013), கொங்குநாடு கலை அறிவியல் கல்லூரி, கோவை, கதைத்தமிழ் ஆய்வு மாநாட்டிற்கு ஆய்வுக் கட்டுரை வழங்கியமைக்காகக் "கதை ஆய்வுச்சுடர் விருது" (2015), கவியரசர் கலைத் தமிழ்ச் சங்கம் "பேராசிரியர் ரத்னா விருது" (2018) ஆசிரியர் தின விழாவில் வழங்கியது.

பொருநை இலக்கியக் களம் மற்றும் சான்லாக்ஸ் பன்னாட்டுத் தமிழியல் ஆய்விதழ் நடத்திய பன்னாட்டுக் கருத்தரங்கிற்கு ஆய்வுக் கட்டுரை வழங்கியமைக்காகத் "தமிழ் இலக்கிய வித்தகர் விருது" (2019) பெற்றார். குறிஞ்சிக் கபிலர் தமிழ்ச் சங்கம் சேவைத் தொண்டினைப் பாராட்டி 70வது குடியரசு தின விழாவில் "சாதனைச் செம்மல் விருது" (2019) பெற்றார்.

மாணவர்களை ஊக்கப்படுத்திக் கட்டுரை எழுத வைத்தமையைப் பாராட்டி "சேவா ரத்னா விருது" (2019) கவியரசர் கலைத் தமிழ்ச் சங்கம் வழங்கியது. உலகத் திருக்குறள் மாநாடு மலேசியா பல்கலைக்கழகத்திற்குக் கட்டுரை வழங்கியமைக்குப் "பேராளர் நினைவுப் பரிசு" (2019) பெற்றார். அனைத்திந்திய அறிவியல் தமிழ்க் கழகம் தஞ்சையில் நடத்திய 25 வெள்ளிவிழா கருத்தரங்கிற்கு ஆய்வுக் கட்டுரை வழங்கியமைக்காக "நினைவுப் பேழை" (2019) ஆகிய விருதுகளைப் பெற்றவர்.

அகிலம் போற்றும் ஆசிரியர்கள் எனும் தலைப்பில் வகுப்பறை பள்ளிக் கல்வி இதழுடன் மதுரை காமராசர் பல்கலைக்கழகம் நடத்திய கருத்தரங்கில் சிறந்த கட்டுரை வழங்கியமையைப் பாராட்டி "சிலம்பொலி செல்லப்பனார் விருது" (2019) பெற்றார்.

உலக ஆசிரியர் தினத்தை முன்னிட்டு கல்விப் பணியில் சிறந்து விளங்கியமையைப் பாராட்டி கலை இலக்கிய ஆய்வு மையம், கும்பகோணம் "பேராசிரியர் சிகரம் விருது" (2020) வழங்கியது.

தமிழ்ப்பணியினையும், தனித்திறனையும் பாராட்டி தமிழ்நாடு கலை இலக்கிய கழகம், கொட்டாரம் "தமிழ் ரத்னா விருது" (2020) வழங்கி சிறப்பித்தது.

கல்லூரி மாணவ, மாணவியர்கள் எளிமையாகப் புரிந்து கொள்ளும் வகையில் தொல்காப்பியம் சொல்லதிகாரம் வினா விடை புத்தகம் 2021இல் வெளியிட்டுள்ளார்.

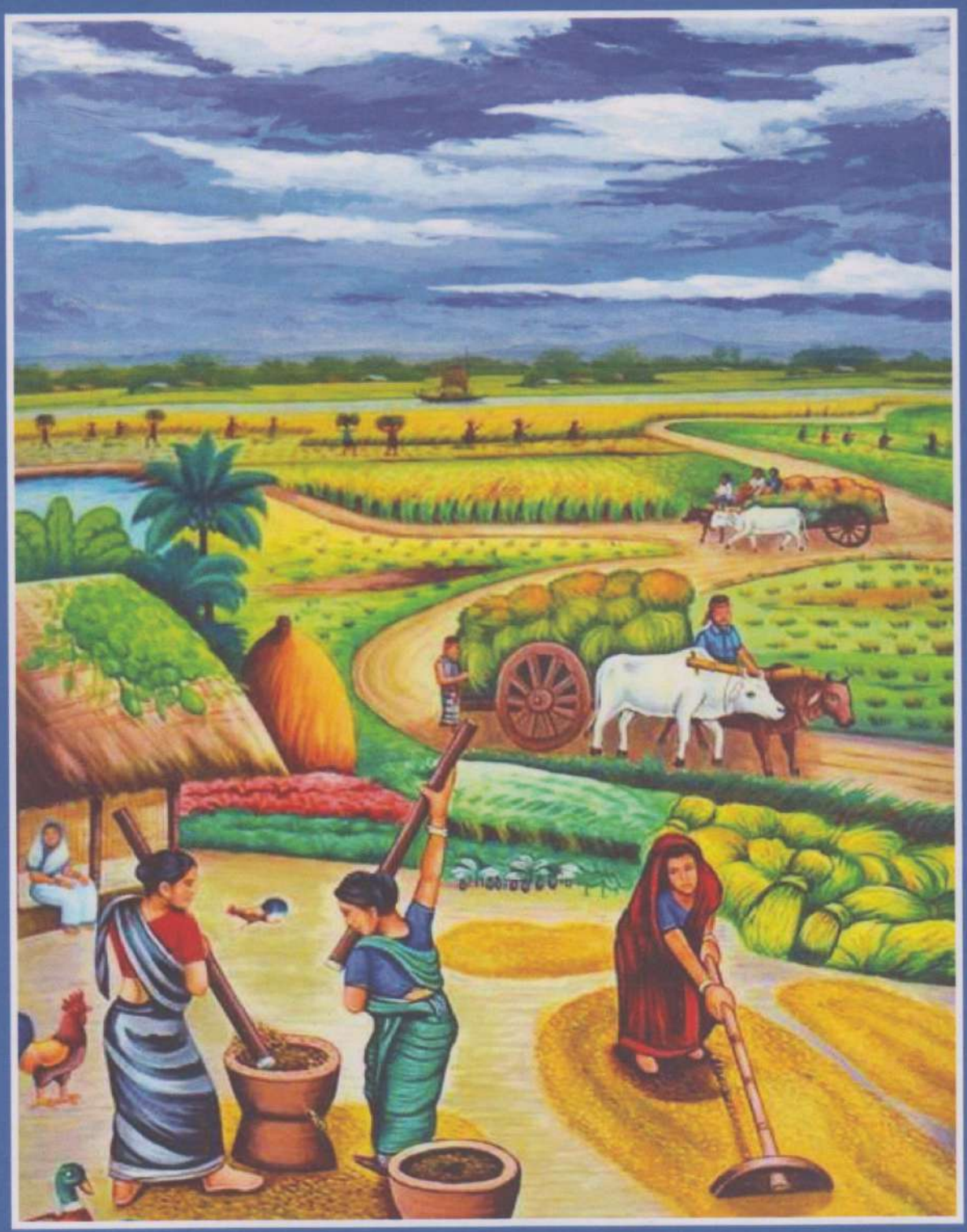
ஆய்வுப்பணியில் சிறந்து விளங்கியமைக்கு மருதம் கலை இலக்கிய ஆய்வு மையம், கும்பகோணம் "ஆய்வாளர் செம்மல் விருது" (2021) வழங்கியது.

பாரதி பதிப்பகம்



ISBN: 978-93-94187-66-5
9 789394 187665
விலை: ₹100

ஆற்றுப்படை நூல்களில் வானியல் சிந்தனைகள்



முனைவர் மு. சுபாஷினி

ஆற்றுப்படை நூல்களில் வானியல் சிந்தனைகள்

முனைவர் மு.சுபாஷினி

முதற்பதிப்பு : ஜூன் 2022

வெளியீடு : பரிதி பதிப்பகம்
56சி/128. பாரத கோயில் அருகில், ஜோலார்பேட்டை,
திருப்பத்தூர் மாவட்டம் - 635 851
மின்னஞ்சல் : Parithijpt@gmail.com

அச்சாக்கம் : மணி ஆப்செட், சென்னை
ஒளி அச்சு : தங்கம் கிராஃபிக்ஸ்

பக்கங்கள் : 88
விலை: ரூ.100

Attupadai Noolkalil Vaniyal Sindanaigal

Dr.M.Subashini

First Edition - June 2022

Parithi Pathippagam
Published by Parithi Pathippagam
56C/128, Near Bharatha Kovil, Jolarpettai,
Tirupattur District-635851 Cell: 72006 93200
Email: Parithijpt@gmail.com

Printed at: clictoprint | *Chennai-600 018.*
Layout: Thangam Graphics, Chennai

Pages : 88
Price : Rs. 100

ISBN No : 978-93-94187-67-2

NATIONAL COLLEGE
(Autonomous)
College with Potential for Excellence
Nationally Re-accredited at 'A+' Grade by NAAC
Unit of Dr.V. Krishnamurthy Educational Foundation

Dr. R. Sundararaman, M.Com., B.Ed., Ph.D.
Principal



வாழ்த்துரை

திருமதி. பேரா. முனைவர் மு.சுபாஷினி [உதவிப்பேராசிரியர், (நிர்வாக நியமனம்) தமிழாய்வுத்துறை, தேசியக்கல்லூரி (தன்னாட்சி), திருச்சிராப்பள்ளி – 1.] அவர்கள் எம் தமிழாய்வுத்துறையில் உதவிப்பேராசிரியர். அவருடைய, 'ஆற்றுப்படை நூல்களில் வானியல் சிந்தனைகள்' எனும் தலைப்பிலான இந்நூலினை முழுமையாகப் படித்தேன் / சுவைத்தேன் / மகிழ்ந்தேன்.

மிக எளிய ஆற்றொழுக்கான நடையில் ஆற்றுப்படை நூல்களில் காணப்பெறும் வானியல் சிந்தனைகளைத் தொகுத்து ஆராய்ந்தளித்துள்ளார் நூலாசிரியர்.

சங்க இலக்கியங்கள் வானத்து மீன்களை நாள்மீன் என்றும் கோள்மீன் என்றும் பகுத்தது எண்ணத்தக்கது. தாமே ஒளி வீசக் கூடியன நாள் மீன் என்றும் சூரியனின் ஒளியால் ஒளி வீசக் கூடியன கோள் மீன் என்றும் வகுக்கப் பெற்றன. அவ்வடிப்படையில் நோக்கின், அசுவனி, பரணி என்று இன்று சொல்லப்பெறும் 27 நட்சத்திரங்களும் அன்றைய நாள் மீனாகும். அவ்வாறே திங்கள், செவ்வாய் என்பவை கோள் மீன்களாகும். இதை ஆற்றுப்படை நூல்கள் விரிவாகச் சொல்கின்றன. அதாவது ஒருவர் பிறக்கும் நாளில் திங்கள் எந்த மீன் (நட்சத்திரத்து) இடத்து இருந்ததோ அந்த நாளே நாள் மீனாகும். இவ்வாறான வானியல் சிந்தனைகளை இந்நூல் வழி உணரமுடிகிறது.

'வான்' – என்ற சொல்லிற்குரிய சொல், பொருள் ஆய்வு, வானிலை ஆய்வு, வானிலை உரு மாற்றம், வானிலை முன் அறிவிப்பு, வானிலை நுட்பங்கள், வகைமைப்பாடு, கோள்களின் நிலைமைகள் என்பன போன்ற உட்தலைப்புகளில் கருத்துக்களைப் பகுத்தும் தொகுத்தும் நூலாசிரியர் அளித்துள்ளார்.

நூலாசிரியர் முனைவர் திருமதி. மு.சுபாஷினி அவர்கள் மேன்மேலும் நூல்கள் பல எழுத வாழ்த்துகிறேன் / பாராட்டுகிறேன்.

தமிழ்கூறு நல்லுலகு இந்நூலினை ஏற்றுப் போற்றிட வேண்டுகிறேன்.

21/1/21
முதல்வர்

TIRUCHY - DINDIGUL ROAD, KARUMANDAPAM, TIRUCHIRAPPALLI - 620 001
Mobile :94431 87019 / E.Mail : principalrsr@nct.ac.in / Phone : 0431 - 2428995 / Fax : 0431 - 2481997

பொருளடக்கம்

வ. எண்	தலைப்பு	பக்க எண்
1	வான் - சொல்லாய்வு	8
2	வானியல்	10
3	வானிலை	12
4	வானம்	19
5	ஞாயிறு	27
6	கோள்கள்	38
7	திங்கள்	40
8	திங்கள் பிறை	45
9	திங்கள் மறைப்பு	47
10	வெள்ளி	50
11	விண்மீன்	52
12	குறுங்கோள்	57
13	மேகம்	59
14	இடி	68
15	மின்னல்	70
16	வானவில்	73
	தொகுப்புரை	77
	சான்றெண் விளக்கம்	80
	துணைநூற்பட்டியல்	82



இந்நூலாசிரியரைப் பற்றி

முனைவர் **மு.சுபாஷினி,**
உதவிப் பேராசிரியர் (நிர்வாக நியமனம்),
தமிழாய்வுத்துறை, தேசியக்கல்லூரி (தன்னாட்சி),
திருச்சிராப்பள்ளி - 01.

முனைவர் மு.சுபாஷினி மணப்பாறை வட்டம் தொப்பம்பட்டி என்னும் கிராமத்தில் பிறந்தவர். போக்குவரத்து வசதி இல்லா ஊரில் இடைநிலைக் கல்விக்குமேல் தொடர்ந்து மேற்படிப்பைப் படித்த முதல் பெண்மணி ஆவார். எம்.ஏ.,பி.எட்., எம்ஃபில்., பிஜிடிசிஏ., பிஎச்.டி., ஆகிய பட்டங்களைப் பெற்றவர்.

முதுகலைப் பயிலும் போதே ஆராய்ச்சிக் கட்டுரை எழுதத் தொடங்கியவர். எண்பதுக்கும் மேற்பட்ட ஆய்வுக் கட்டுரைகளைப் பல்வேறு கல்லூரிகளுக்கு வழங்கியுள்ளார்.

கவியரசர் கலைத் தமிழ்ச் சங்கம் நடத்திய மாநில அளவிலான கட்டுரைப் போட்டியில் "இலக்கியச் சுடர் விருது" (2011), குறிஞ்சிக் கபிலர் தமிழ்ச் சங்கம் நடத்திய மாநில அளவிலான ஓவியப் போட்டியில் "வரைகலை வளர்மணி விருது" (2013), கொங்குநாடு கலை அறிவியல் கல்லூரி, கோவை, கதைத்தமிழ் ஆய்வு மாநாட்டிற்கு ஆய்வுக் கட்டுரை வழங்கியமைக்காகக் "கதை ஆய்வுச்சுடர் விருது" (2015), கவியரசர் கலைத் தமிழ்ச் சங்கம் "பேராசிரியர் ரத்னா விருது" (2018) ஆசிரியர் தின விழாவில் வழங்கியது.

பொருநை இலக்கியக் களம் மற்றும் சான்லாக்ஸ் பன்னாட்டுத் தமிழியல் ஆய்விதழ் நடத்திய பன்னாட்டுக் கருத்தரங்கிற்கு ஆய்வுக் கட்டுரை வழங்கியமைக்காகத் "தமிழ் இலக்கிய வித்தகர் விருது" (2019) பெற்றார். குறிஞ்சிக் கபிலர் தமிழ்ச் சங்கம் சேவைத் தொண்டினைப் பாராட்டி 70வது குடியரசு தின விழாவில் "சாதனைச் செம்மல் விருது" (2019) பெற்றார்.

மாணவர்களை ஊக்கப்படுத்திக் கட்டுரை எழுத வைத்தமையைப் பாராட்டி "சேவா ரத்னா விருது" (2019) கவியரசர் கலைத் தமிழ்ச் சங்கம் வழங்கியது. உலகத் திருக்குறள் மாநாடு மலேசியா பல்கலைக்கழகத்திற்குக் கட்டுரை வழங்கியமைக்குப் "பேராளர் நினைவுப் பரிசு" (2019) பெற்றார். அனைத்திந்திய அறிவியல் தமிழ்க் கழகம் தஞ்சையில் நடத்திய 25 வெள்ளிவிழா கருத்தரங்கிற்கு ஆய்வுக் கட்டுரை வழங்கியமைக்காக "நினைவுப் பேழை" (2019) ஆகிய விருதுகளைப் பெற்றவர்.

அகிலம் போற்றும் ஆசிரியர்கள் எனும் தலைப்பில் வகுப்பறை பள்ளிக் கல்வி இதழுடன் மதுரை காமராசர் பல்கலைக்கழகம் நடத்திய கருத்தரங்கில் சிறந்த கட்டுரை வழங்கியமையைப் பாராட்டி "சிலம்பொலி செல்லப்பனார் விருது" (2019) பெற்றார்.

உலக ஆசிரியர் தினத்தை முன்னிட்டு கல்விப் பணியில் சிறந்து விளங்கியமையைப் பாராட்டி கலை இலக்கிய ஆய்வு மையம், கும்பகோணம் "பேராசிரியர் சிகரம் விருது" (2020) வழங்கியது.

தமிழ்ப்பணியினையும், தனித்திறனையும் பாராட்டி தமிழ்நாடு கலை இலக்கிய கழகம், கொட்டாரம் "தமிழ் ரத்னா விருது" (2020) வழங்கி சிறப்பித்தது.

கல்லூரி மாணவ, மாணவியர்கள் எளிமையாகப் புரிந்து கொள்ளும் வகையில் தொல்காப்பியம் சொல்லதிகாரம் வினா விடை புத்தகம் 2021இல் வெளியிட்டுள்ளார்.

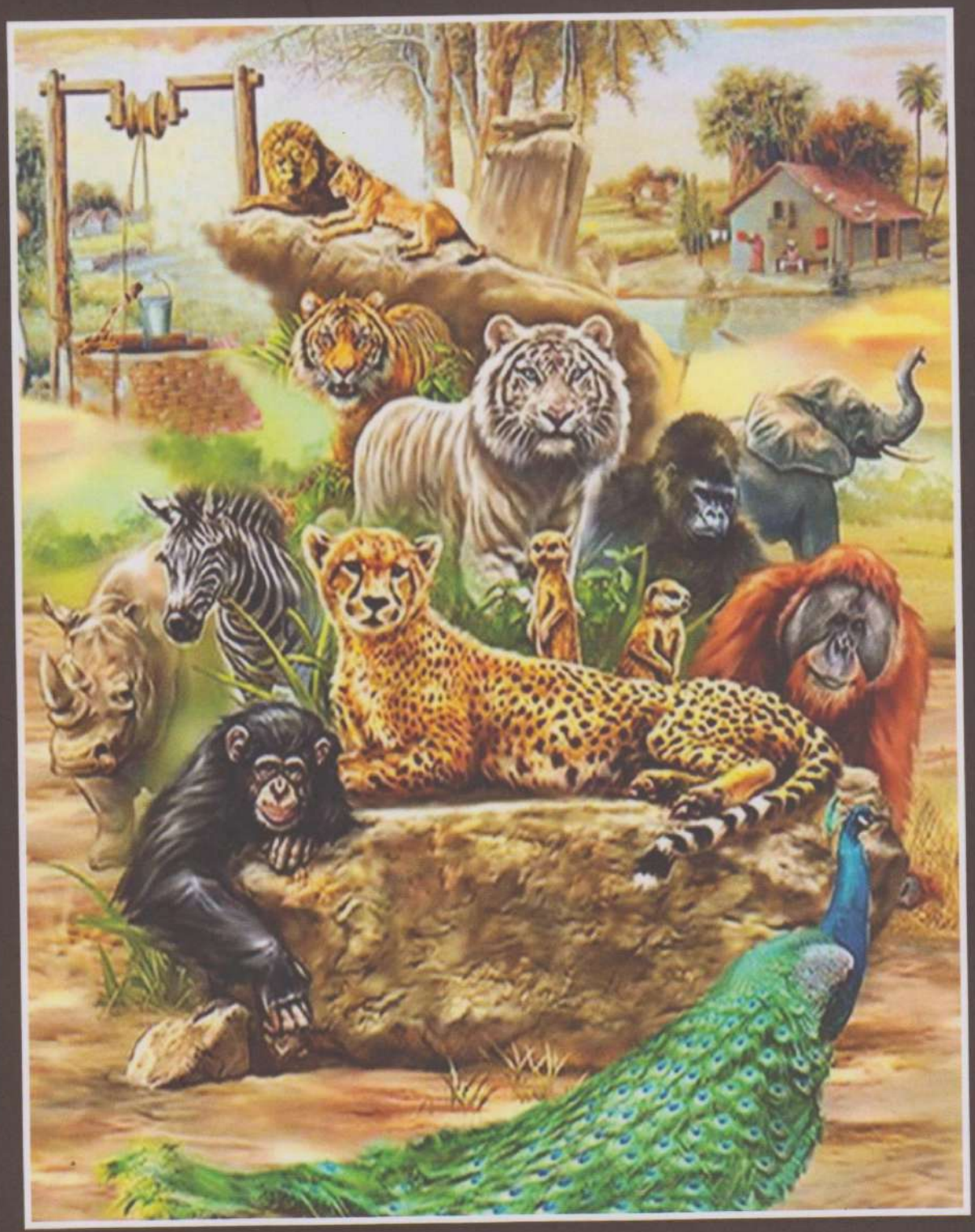
ஆய்வுப்பணியில் சிறந்து விளங்கியமைக்கு மருதம் கலை இலக்கிய ஆய்வு மையம், கும்பகோணம் "ஆய்வாளர் செம்மல் விருது" (2021) வழங்கியது.

பரிதி பதிப்பகம்



ISBN: 978-93-94187-67-2
9 789394 187672
விலை: ₹ 100

ஆற்றுப்படை நூல்களில் விலங்கியல் சிந்தனைகள்



முனைவர் மு. சுபாஷினி

ஆற்றுப்படை நூல்களில் விலங்கியல் சிந்தனைகள்

முனைவர் மு.சுபாஷினி

முதற்பதிப்பு : ஜூன் 2022

வெளியீடு : பரிதி பதிப்பகம்
56சி/128. பாரத கோயில் அருகில், ஜோலார்பேட்டை,
திருப்பத்தூர் மாவட்டம் - 635 851
மின்னஞ்சல் : Parithijpt@gmail.com

அச்சாக்கம் : மணி ஆப்செட், சென்னை
ஒளி அச்சு : தங்கம் கிராஃபிக்ஸ்

பக்கங்கள் : 104
விலை: ரூ.100

Attupadai Noolkalil Vilankiyal Sindanaigal

Dr.M.Subashini

First Edition - June 2022

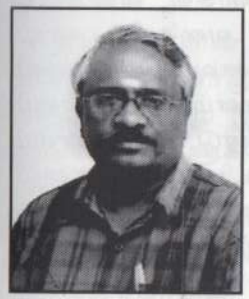
Parithi Pathippagam
Published by Parithi Pathippagam
56C/128, Near Bharatha Kovil, Jolarpettai,
Tirupattur District-635851 Cell: 72006 93200
Email: Parithijpt@gmail.com

Printed at: clictoprint | *Chennai-600 018.*
Layout: Thangam Graphics, Chennai

Pages : 104
Price : Rs. 100

ISBN No : 978-93-94187-59-7

வாழ்த்துரை



முனைவர் **க.அன்பழகன்**
தமிழ்ப்பேராசிரியர் -
தமிழ்ப்பிரிவு
தொலைதூரக் கல்வி இயக்ககம்
அண்ணாமலைப்
பல்கலைக்கழகம்
அண்ணாமலைநகர்.

தமிழ் இலக்கிய ஆய்வுக் களத்தில் மேற்கொள்ளப்படும் ஆய்வுகளில் தனித்துவம் மிக்கது அறிவியல் தமிழ் பார்வைகொண்டு ஆராயப்படும் ஆய்வுகள். ஒரு மொழியின் நிலைபேற்றுத் தன்மைக்கான காரணங்களில் அதன் அறிவியல் தன்மையும் முக்கிய காரணமாக இலங்குகிறது என்பதை உறுதியாகக் குறிப்பிடலாம். நான்காவது தமிழாக அடையாளப்படுத்தப்பட்டு இயங்கும் அறிவியல் தமிழ் அளப்பரிய வளர்ச்சியை நோக்கிய பாதையில் பயணித்துவருவதும் கவனிக்கத்தக்கது. அவ்வகையில் இந்நூல் ஆற்றுப்படை நூல்களில் அறிவியல் சிந்தனைகள் என்கிற பொருண்மை தளத்தில் விலங்கியல் குறித்த அறிவியல் கருத்துகளை ஆராய்ந்து வெளிப்படுத்துகிறது. ஆற்றுப்படை நூல்கள் முழுக்க இருக்கும் அறிவியல் சிந்தனைகளைக் கண்கொண்டு பார்த்து அவற்றில் ஒவ்வொரு பிரிவாக ஆராய்ந்து வெளிப்படுத்துவது என்பது ஒரு மதிப்புமிக்க தமிழ்த்தொண்டாகவே கருதப்படவேண்டும். அது பாராட்டப்படவும் வேண்டும் என்பதற்கு இந்நூல் ஒரு சிறந்த சான்றாகும்.

பொருளடக்கம்

வ. எண்	தலைப்பு	பக்க எண்
1	முகவுரை	11
2	விலங்கியல்	12
3	தாவர உண்ணி	13
4	ஊன் உண்ணி	32
5	கொறிக்கும் உண்ணி	50
6	கணுக்காலிகள்	55
7	ஊர்வன	66
8	நீர் வாழ்வன	77
9	பறப்பன	85
10	தொகுப்புரை	92
11	சான்றெண் விளக்கம்	95
12	துணைநூற்பட்டியல்	98
13	பின்னிணைப்புகள்	102



இந்நூலாசிரியரைப் பற்றி

முனைவர் **மு.சுபாஷினி,**
உதவிப் பேராசிரியர் (நிர்வாக நியமனம்),
தமிழாய்வுத்துறை, தேசியக்கல்லூரி (தன்னாட்சி),
திருச்சிராப்பள்ளி - 01.

முனைவர் மு.சுபாஷினி மணப்பாறை வட்டம் தொப்பம்பட்டி என்னும் கிராமத்தில் பிறந்தவர். போக்குவரத்து வசதி இல்லா ஊரில் இடைநிலைக் கல்விக்குமேல் தொடர்ந்து மேற்படிப்பைப் படித்த முதல் பெண்மணி ஆவார். எம்.ஏ.,பி.எட்., எம்ஃபில்., பிஜிடிசிஏ., பிஎச்.டி., ஆகிய பட்டங்களைப் பெற்றவர்.

முதுகலைப் பயிலும் போதே ஆராய்ச்சிக் கட்டுரை எழுதத் தொடங்கியவர். எண்பதுக்கும் மேற்பட்ட ஆய்வுக் கட்டுரைகளைப் பல்வேறு கல்லூரிகளுக்கு வழங்கியுள்ளார்.

கவியரசர் கலைத் தமிழ்ச் சங்கம் நடத்திய மாநில அளவிலான கட்டுரைப் போட்டியில் "இலக்கியச் சுடர் விருது" (2011), குறிஞ்சிக் கபிலர் தமிழ்ச் சங்கம் நடத்திய மாநில அளவிலான ஓவியப் போட்டியில் "வரைகலை வளர்மணி விருது" (2013), கொங்குநாடு கலை அறிவியல் கல்லூரி, கோவை, கதைத்தமிழ் ஆய்வு மாநாட்டிற்கு ஆய்வுக் கட்டுரை வழங்கியமைக்காகக் "கதை ஆய்வுச்சுடர் விருது" (2015), கவியரசர் கலைத் தமிழ்ச் சங்கம் "பேராசிரியர் ரத்னா விருது" (2018) ஆசிரியர் தின விழாவில் வழங்கியது.

பொருநை இலக்கியக் களம் மற்றும் சான்லாக்ஸ் பன்னாட்டுத் தமிழியல் ஆய்விதழ் நடத்திய பன்னாட்டுக் கருத்தரங்கிற்கு ஆய்வுக் கட்டுரை வழங்கியமைக்காகத் "தமிழ் இலக்கிய வித்தகர் விருது" (2019) பெற்றார். குறிஞ்சிக் கபிலர் தமிழ்ச் சங்கம் சேவைத் தொண்டினைப் பாராட்டி 70வது குடியரசு தின விழாவில் "சாதனைச் செம்மல் விருது" (2019) பெற்றார்.

மாணவர்களை ஊக்கப்படுத்திக் கட்டுரை எழுத வைத்தமையைப் பாராட்டி "சேவா ரத்னா விருது" (2019) கவியரசர் கலைத் தமிழ்ச் சங்கம் வழங்கியது. உலகத் திருக்குறள் மாநாடு மலேசியா பல்கலைக்கழகத்திற்குக் கட்டுரை வழங்கியமைக்குப் "பேராளர் நினைவுப் பரிசு" (2019) பெற்றார். அனைத்திந்திய அறிவியல் தமிழ்க் கழகம் தஞ்சையில் நடத்திய 25 வெள்ளிவிழா கருத்தரங்கிற்கு ஆய்வுக் கட்டுரை வழங்கியமைக்காக "நினைவுப் பேழை" (2019) ஆகிய விருதுகளைப் பெற்றவர்.

அகிலம் போற்றும் ஆசிரியர்கள் எனும் தலைப்பில் வகுப்பறை பள்ளிக் கல்வி இதழுடன் மதுரை காமராசர் பல்கலைக்கழகம் நடத்திய கருத்தரங்கில் சிறந்த கட்டுரை வழங்கியமையைப் பாராட்டி "சிலம்பொலி செல்லப்பனார் விருது" (2019) பெற்றார்.

உலக ஆசிரியர் தினத்தை முன்னிட்டு கல்விப் பணியில் சிறந்து விளங்கியமையைப் பாராட்டி கலை இலக்கிய ஆய்வு மையம், கும்பகோணம் "பேராசிரியர் சிகரம் விருது" (2020) வழங்கியது.

தமிழ்ப்பணியினையும், தனித்திறனையும் பாராட்டி தமிழ்நாடு கலை இலக்கிய கழகம், கொட்டாரம் "தமிழ் ரத்னா விருது" (2020) வழங்கி சிறப்பித்தது.

கல்லூரி மாணவ, மாணவியர்கள் எளிமையாகப் புரிந்து கொள்ளும் வகையில் தொல்காப்பியம் சொல்லதிகாரம் வினா விடை புத்தகம் 2021இல் வெளியிட்டுள்ளார்.

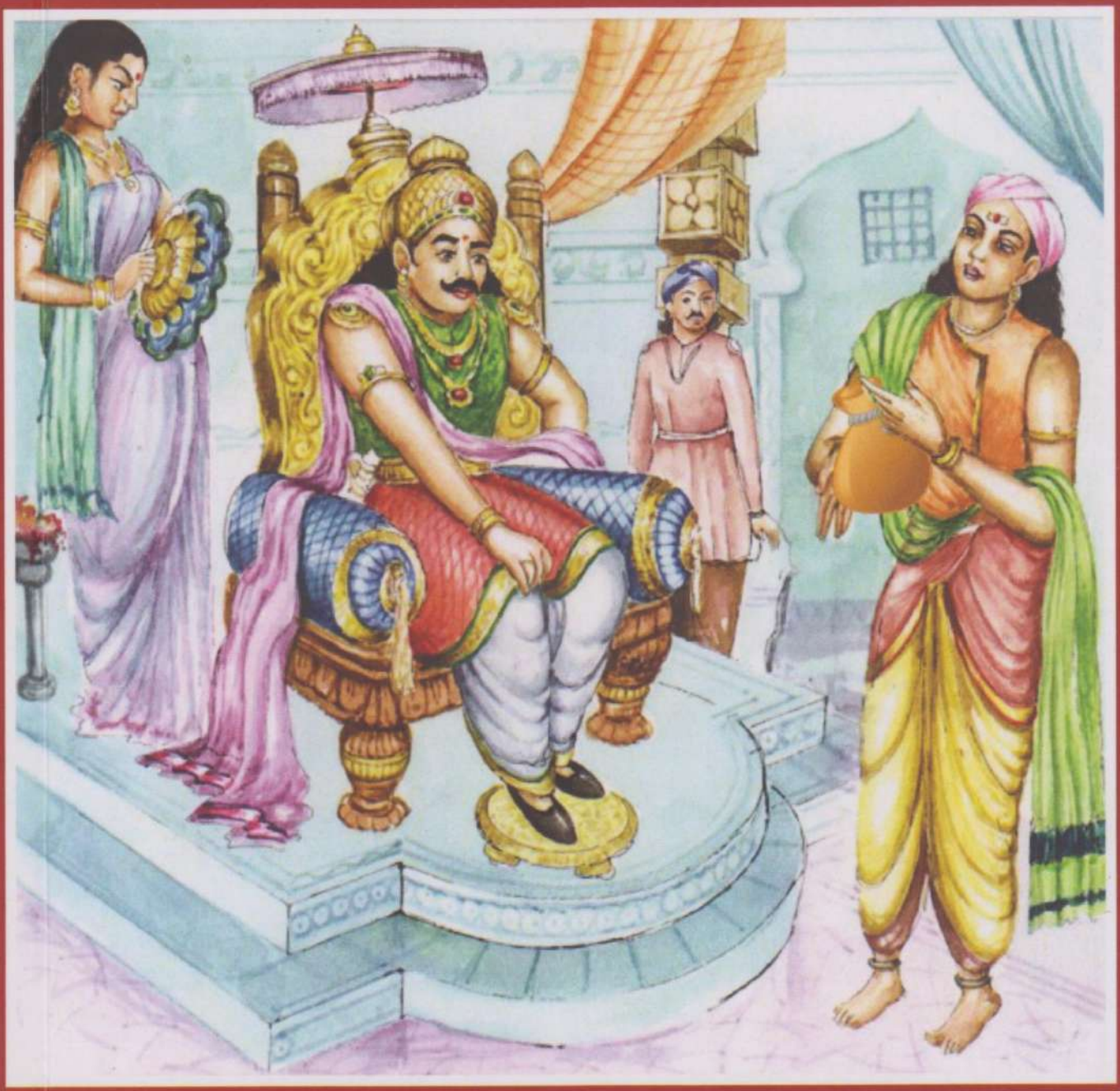
ஆய்வுப்பணியில் சிறந்து விளங்கியமைக்கு மருதம் கலை இலக்கிய ஆய்வு மையம், கும்பகோணம் "ஆய்வாளர் செம்மல் விருது" (2021) வழங்கியது.

பரிதி பதிப்பகம்



ISBN: 978-93-94187-59-7
9 789394 187597
விலை: ₹100

ஆற்றுப்படை நூல்களின் சிறப்புகள்



முனைவர் மு. சுபாஷினி

ஆற்றுப்படை நூல்களின் சிறப்புகள்

முனைவர் மு.சுபாஷினி

முதற்பதிப்பு : ஜூன் 2022

வெளியீடு : பரிதி பதிப்பகம்
56சி/128. பாரத கோயில் அருகில், ஜோலார்பேட்டை,
திருப்பத்தூர் மாவட்டம் - 635 851
மின்னஞ்சல் : Parithijpt@gmail.com

அச்சாக்கம் : மணி ஆப்செட், சென்னை
ஒளி அச்சு : தங்கம் கிராஃபிக்ஸ்

பக்கங்கள் : 88
விலை: ரூ.100

Attupadai Noolkalin Sirappugal

Dr.M.Subashini

First Edition - June 2022

Parithi Pathippagam
Published by Parithi Pathippagam
56C/128, Near Bharatha Kovil, Jolarpettai,
Tirupattur District-635851 Cell: 72006 93200
Email: Parithijpt@gmail.com

Printed at: clictoprint | *Chennai-600 018.*
Layout: Thangam Graphics, Chennai

Pages : 88
Price : Rs. 100

ISBN No : 978-93-94187-78-8

வாழ்த்துரை



முனைவர் **ந.மாணிக்கம்**
இணைப்பேராசிரியர்
தமிழாய்வுத்துறை,
தேசியக்கல்லூரி (தன்னாட்சி),
திருச்சிராப்பள்ளி - 01

தமிழ்மொழிச் செம்மாந்து சிறப்புற இயங்குவதற்கு முதற்காரணமாக விளங்குவது இலக்கியங்கள் ஆகும். மக்கள் வாழ்ந்த முறையையும் வாழும் முறையையும் எடுத்துக் காட்டும் உயர்ந்த பெட்டகமாக இலக்கியங்கள் அமைந்துள்ளன.. பண்டைக்கால மக்கள் கடைபிடித்த பண்பாடு, கலாச்சாரத்தை இன்றளவிலும் நம் வாழ்வில் பயன்படுத்தி வருகிறோம் என்றால் அதற்கு இலக்கியங்களில் புலவர்கள் பதிவு செய்துள்ளமையேயாகும்.

சங்க இலக்கியங்களில் பத்துப்பாட்டிலுள்ள ஆற்றுப்படை நூல்கள் சங்ககால மக்களின் வாழ்வைப் படம்பிடித்துக் காட்டுவனபோல அமைந்துள்ளன. மனித வாழ்க்கையில் தன்னலம் கருதாமல் பிறர் நலத்தையே பேணிகாத்த பேராண்மையை இந்நூல்களின் வாயிலாகக் காண முடிகின்றன.

மன்னர்களும், வள்ளல்களும் தாம் செல்வ வளத்தோடு இருந்தும், தன்னை நாடி வரும் புலவர்களையும், மக்களையும் தம் உறவாகக் கொண்டு அவர்களுக்கு வேண்டுவனவற்றை அளித்து, இல்லாமையை இல்லாமல்

பொருளடக்கம்

வ. எண்	தலைப்பு	பக்க எண்
	முகவுரை	11
1	ஆற்றுப்படை விளக்கம்	12
2	தொல்காப்பியத்தில் ஆற்றுப்படை	15
3	திருமுருகாற்றுப்படையின் சிறப்புகள்	18
4	பன்னிரு கைகளின் சிறப்புகள்	23
5	பொருநராற்றுப்படையின் சிறப்புகள்	30
6	இசையின் சிறப்புகள்	32
7	இசைக்கருவிகள்	32
8	கரிகாலனின் சிறப்புகள்	36
9	சிறுபாணாற்றுப்படையின் சிறப்புகள்	45
10	சீறியாழின் சிறப்புகள்	53
11	பெரும்பாணாற்றுப்படையின் சிறப்புகள்	56
12	ஆட்சிச் சிறப்பு	58
13	மலைபடுகடாத்தின் சிறப்புகள்	66
14	நூலின் தனிச்சிறப்புகள்	68
15	மலையில் கேட்கும் ஓசைகள்	75
	தொகுப்புரை	80
	சான்றெண் விளக்கம்	82
	துணைநூற்பட்டியல்	84



இந்நூலாசிரியரைப் பற்றி

முனைவர் **மு.சுபாஷினி,**
உதவிப் பேராசிரியர் (நிர்வாக நியமனம்),
தமிழாய்வுத்துறை, தேசியக்கல்லூரி (தன்னாட்சி),
திருச்சிராப்பள்ளி - 01.

முனைவர் மு.சுபாஷினி மணப்பாறை வட்டம் தொப்பம்பட்டி என்னும் கிராமத்தில் பிறந்தவர். போக்குவரத்து வசதி இல்லா ஊரில் இடைநிலைக் கல்விக்குமேல் தொடர்ந்து மேற்படிப்பைப் படித்த முதல் பெண்மணி ஆவார். எம்.ஏ.,பி.எட்., எம்ஃபில்., பிஜிடிசிஏ., பிஎச்.டி., ஆகிய பட்டங்களைப் பெற்றவர்.

முதுகலைப் பயிலும் போதே ஆராய்ச்சிக் கட்டுரை எழுதத் தொடங்கியவர். எண்பதுக்கும் மேற்பட்ட ஆய்வுக் கட்டுரைகளைப் பல்வேறு கல்லூரிகளுக்கு வழங்கியுள்ளார்.

கவியரசர் கலைத் தமிழ்ச் சங்கம் நடத்திய மாநில அளவிலான கட்டுரைப் போட்டியில் "இலக்கியச் சுடர் விருது" (2011), குறிஞ்சிக் கபிலர் தமிழ்ச் சங்கம் நடத்திய மாநில அளவிலான ஓவியப் போட்டியில் "வரைகலை வளர்மணி விருது" (2013), கொங்குநாடு கலை அறிவியல் கல்லூரி, கோவை, கதைத்தமிழ் ஆய்வு மாநாட்டிற்கு ஆய்வுக் கட்டுரை வழங்கியமைக்காகக் "கதை ஆய்வுச்சுடர் விருது" (2015), கவியரசர் கலைத் தமிழ்ச் சங்கம் "பேராசிரியர் ரத்னா விருது" (2018) ஆசிரியர் தின விழாவில் வழங்கியது.

பொருநை இலக்கியக் களம் மற்றும் சான்லாக்ஸ் பன்னாட்டுத் தமிழியல் ஆய்விதழ் நடத்திய பன்னாட்டுக் கருத்தரங்கிற்கு ஆய்வுக் கட்டுரை வழங்கியமைக்காகத் "தமிழ் இலக்கிய வித்தகர் விருது" (2019) பெற்றார். குறிஞ்சிக் கபிலர் தமிழ்ச் சங்கம் சேவைத் தொண்டினைப் பாராட்டி 70வது குடியரசு தின விழாவில் "சாதனைச் செம்மல் விருது" (2019) பெற்றார்.

மாணவர்களை ஊக்கப்படுத்திக் கட்டுரை எழுத வைத்தமையைப் பாராட்டி "சேவா ரத்னா விருது" (2019) கவியரசர் கலைத் தமிழ்ச் சங்கம் வழங்கியது. உலகத் திருக்குறள் மாநாடு மலேசியா பல்கலைக்கழகத்திற்குக் கட்டுரை வழங்கியமைக்குப் "பேராளர் நினைவுப் பரிசு" (2019) பெற்றார். அனைத்திந்திய அறிவியல் தமிழ்க் கழகம் தஞ்சையில் நடத்திய 25 வெள்ளிவிழா கருத்தரங்கிற்கு ஆய்வுக் கட்டுரை வழங்கியமைக்காக "நினைவுப் பேழை" (2019) ஆகிய விருதுகளைப் பெற்றவர்.

அகிலம் போற்றும் ஆசிரியர்கள் எனும் தலைப்பில் வகுப்பறை பள்ளிக் கல்வி இதழுடன் மதுரை காமராசர் பல்கலைக்கழகம் நடத்திய கருத்தரங்கில் சிறந்த கட்டுரை வழங்கியமையைப் பாராட்டி "சிலம்பொலி செல்லப்பனார் விருது" (2019) பெற்றார்.

உலக ஆசிரியர் தினத்தை முன்னிட்டு கல்விப் பணியில் சிறந்து விளங்கியமையைப் பாராட்டி கலை இலக்கிய ஆய்வு மையம், கும்பகோணம் "பேராசிரியர் சிகரம் விருது" (2020) வழங்கியது.

தமிழ்ப்பணியினையும், தனித்திறனையும் பாராட்டி தமிழ்நாடு கலை இலக்கிய கழகம், கொட்டாரம் "தமிழ் ரத்னா விருது" (2020) வழங்கி சிறப்பித்தது.

கல்லூரி மாணவ, மாணவியர்கள் எளிமையாகப் புரிந்து கொள்ளும் வகையில் தொல்காப்பியம் சொல்லதிகாரம் வினா விடை புத்தகம் 2021இல் வெளியிட்டுள்ளார்.

ஆய்வுப்பணியில் சிறந்து விளங்கியமைக்கு மருதம் கலை இலக்கிய ஆய்வு மையம், கும்பகோணம் "ஆய்வாளர் செம்மல் விருது" (2021) வழங்கியது.

பரிதி பதிப்பகம்



ISBN: 978-93-94187-78-8
9 789394 187788
விலை: ₹100


செங்காந்தள் – இயற்கை
முனைவர் த.மகேஸ்வரி & முனைவர் து.சவிதா

Title Verso

TITLE OF THE BOOK	: Senkanthal - Iyarkkai
புத்தகத்தலைப்பு	: செங்காந்தள் - இயற்கை
EDITORS	: Dr. D.Maheswari & Dr. D.Savitha
தொகுப்பாசிரியர்	: முனைவர் த.மகேஸ்வரி & முனைவர் து.சவிதா
FIRST EDITION	: 2021
முதல் பதிப்பு	: 2021
PAGES / பக்கங்கள்	: 90
PRICE / விலை	: 250
ISBN NUMBER	: 978-81-949695-9-4
CONTACT NUMBER	: 8526769556

PUBLISHER : Pandian Educational Trust,
3/350, Veterinary Hospital Backside,
Virudhunagar – 626001.
Tamil Nadu

PRINTER : Maheswari Publishers,
3/350, Veterinary Hospital Rear side,
Virudhunagar – 626001.
Tamil Nadu

பதிப்புரிமை/Copyright © 2021 – Maheswari Publishers

அனைத்து பதிப்புரிமையும் பெறப்பட்டுள்ளது. இப்புத்தகத்தின் எப்பகுதியும் பதிப்பகத்தின் அனுமதியின்றி அச்சிடப்படக்கூடாது.

All rights reserved. No part of this book should be transmitted to any type of printed material without proper permission from the publisher.

இப்புத்தகம் கிரியேட்டிவ் காமன்சு ஆட்ரிபியூசன் 4.0வின் கீழ் பன்னாட்டு உரிமம் பெற்றுள்ளது. The content of the book is licensed under **Creative Commons Attribution4.0** International License.

செங்காந்தள்

குறிஞ்சி நில தெய்வமான முருகனின் அடையாளப்பூ செங்காந்தள்பூ. போர் செய்யும் முருகன் பிறந்த கார்த்திகை மாதத்தில் இதன் பூ அகல்விளக்கு போல பூப்பதால் கார்த்திகைப்பூ என்று அழைக்கப்படுகிறது. *கரும்பு மூசாசச் சுடர்பூங் காந்தள் பெருத்தன் கண்ணி மிலைந்த சென்யன்* என்ற திருமுருகாற்றுப்படை பாடல் வண்டு இனங்கள் மொய்க்காத நல்ல மணமுடைய, நெருப்புப் போன்ற செந்நிறம் மற்றும் குளிர்ச்சியுள்ள செங்காந்தள் பூவாலாகிய குளிர்ச்சியுடைய மாலையை சூடியவன் முருகன் என்று வர்ணிக்கிறது. தமிழர்களின் வீரம் மற்றும் கலாச்சார பெருமையை அடையாளப்படுத்தும்; செங்காந்தள் மலரின் பெயரையே இவ்ஆய்வுநூல் வரிசைக்குச் சூட்டுவதில் அகமகிழ்வடைகிறேன்.

செங்காந்தளின் அழகிய முகை தன் இதழ் விரியும் வரை வண்டுகளைக் காத்திருக்க வைக்காமல் வண்டு வந்தவுடன் அதனை எதிர்நோக்கி தம் இதழை விரித்து தேனைத் தந்து வண்டினை மகிழ்ச்சிப்படுத்தும். செங்காந்தள் தன்னுள் உள்ள தேனை அடக்கி வைத்திருப்பது போன்று கல்தோன்றி மண்தோன்றா காலந்தொட்டே தமிழ்மொழி அரிய இனிய செய்திகளைத் தன்னுள் அடக்கி வைத்துள்ளது. தேனைப் பருக வண்டுகள் அணிவகுப்பது போல் தமிழ் சமூகம் தமிழ்த்தேன் பருக; தமிழ்ப்பேராசிரியர்கள், ஆர்வலர்கள் தங்கள் எழுத்தாற்றலை அர்ப்பணிக்க ஆயத்தமாயுள்ளனர். தமிழ் ஆர்வலர்களுக்காகத் துளிர்விடும் இந்நூல் பயணத்திற்குச் செங்காந்தள் என்று பெயரிட்டது சாலப் பொருந்தும்.

முருகன் என்றால் அழகன். அவன் கார்த்திகை மலரைச்சூடி பேரழகுடன் திகழ்வது போல் தமிழின் பல்வகை இலக்கிய செய்திகளை புதிய ஆய்வு நோக்கத்துடன் தமிழ்மொழியில் மாலையாகத் தொடுத்து வெளிக்கொணர்வதில் இச்செங்காந்தள் பயணம் இனிதே முதல் மலராய் மலர்கிறது.

உள்ளடக்கம்

1. இலக்கியங்களில் பூக்கள் 1-23

முனைவர் து. சவிதா, உதவிப்பேராசிரியர், தமிழ்த்துறை,
பூசாகோஅர கிருஷ்ணம்மாள் மகளிர் கல்லூரி, கோவை.

2. புன்னை மரமும் வரலாற்று நிகழ்வுகளும் 24-38

முனைவர் செ.சாந்தி, கௌரவ விரிவுரையாளர், வரலாற்றுத் துறை,
அழகப்பா பல்கலைக்கழகம், காரைக்குடி.

3. ஆற்றுப்படை நூல்களில் மரங்கள் 39-56

முனைவர் மு.சுபாஷினி, உதவிப்பேராசிரியர், தமிழாய்வுத்துறை,
தேசியக்கல்லூரி, திருச்சிராப்பள்ளி.

4. இலக்கியமும் ஆம்பலும் 57-79

முனைவர் அ. இராஜலட்சுமி, முதுகலை பட்டதாரி ஆசிரியர்,
பாரதி மெட்ரிக்குலேசன் மேல்நிலைப் பள்ளி, கோவை.

இலக்கியங்களில் பூக்கள்

Flowers in Literature

1. இலக்கியங்களில் பூக்கள்

முனைவர் து.சவிதா, உதவிப்பேராசிரியர், தமிழ்த்துறை,
பூசாகோஅர கிருஷ்ணம்மாள் மகளிர் கல்லூரி, கோவை.

2. புன்னை மரமும் வரலாற்று நிகழ்வுகளும்

முனைவர் செ.சாந்தி, கௌரவ விரிவுரையாளர், வரலாற்றுத் துறை
அழகப்பா பல்கலைக்கழகம், காரைக்குடி.

3. ஆற்றுப்படை நூல்களில் மரங்கள்

முனைவர் மு.சுபாஷினி, உதவிப்பேராசிரியர், தமிழாய்வுத்துறை,
தேசியக்கல்லூரி, திருச்சிராப்பள்ளி.

4. இலக்கியமும் ஆம்பலும்

முனைவர் அ.இராஜலட்சுமி, முதுகலை பட்டதாரி ஆசிரியர்,
பாரதி மெட்ரிக்குலேசன் மேல்நிலைப் பள்ளி, கோவை.

புத்தகக்குறிப்பு



9 788194 969594

தொல்காப்பியம்
சொல்லதிகாரம்

வினா-விடை



முனைவர் மு. சுபாஷினி

நூற்குறிப்பு

நூற்பெயர்	:	**தொல்காப்பியம் – சொல்லதிகாரம் வினா – விடை**
ஆசிரியர்	:	முனைவர் **மு. சுபாஷினி**
மொழி	:	தமிழ்
முதற் பதிப்பு	:	2020
பக்கம்	:	x + 98 = 108
எழுத்து	:	12 புள்ளி
தாள்	:	18.1 நேச்சுரல் சேட்
அளவு	:	1/8
படிகள்	:	500
விலை	:	உரூபா : 75/-
உரிமை	:	ஆசிரியருக்கு
வெளியீடு	:	**ஜாசிம் பப்ளிகேசன்** காஜாமலை, திருச்சி-23.
நூலாக்கம்	:	**"தி பிரிண்டிங்கு அவசு"** திருச்சிராப்பள்ளி - 23. 0431-2420121
அலைபேசி	:	90424 53877
ISBN	:	ISBN 978-93-87360-51-8

அணிந்துரை



நாவுக்கரசர்
கலைமாமணி
டாக்டர்.**சோ.சத்தியசீலன்** M.A.,Ph.D

உலக மக்கள் பெயர் மற்றும் மொழிகளுக்குள் பல்லாயிரம் ஆண்டுகள் தன்னுடைய தனித்தன்மையின் பயன்பாட்டுச் சிறப்பும், கட்டுக்கோப்பும் ஒரு சிறிதும் குறையாமல் தன் அழகினை மேலும் வளர்த்துக்கொண்டு இன்றைய நாள்வரை உயர்ந்தோங்கும் மொழி அன்னைத் தமிழாகும். ஏறத்தாழ இரண்டாயிரம் ஆண்டுகளாகத் தன்னால் உலகிற்கு உணர்த்தப்படும் எழுத்துக்களின் அழகும், ஆழமும், விரிவும் சிந்தாமலும் சிதறாமலும் தன்னிடத்தே நூல்கள் வடிவத்தில் பாதுகாத்து வரும் ஓர் ஒப்பற்ற மொழி நம்முடைய அன்னைத் தமிழாகும்.

காலம் என்னும் பேராழியில் நிறுவப்பெற்ற கலங்கரை விளக்குகள் அறிஞர்களுடைய கருத்துக் கருவூலங்கள் ஆகும். அவற்றைக் காலம் என்னும் ஆழியில் காற்று மழை ஊழியிலும் சாகாது கம்பன் பாட்டு அது தலைமுறைக்கு எழுதி வைத்த சீட்டு என்று நூல்கள் குறித்துக் கவியரசர் கண்ணதாசன் அண்மையில் கூறியது மிகமிகப் பழங்காலத்திலேயே வெளியிடப்பட்ட அறிஞர் பெருமக்களுடைய கருத்தாகும். **'கடவுள் குருடாகிவிடுகிறான், தத்துவங்கள் நொண்டி அடிக்கின்றன. இந்த உலகமே ஒரு பேரிருளில் ஆழ்ந்துவிடுகிறது'** என்பது மிகமிக ஆழமான உண்மையான செய்தியாகும். இந்த அழிவுகளெல்லாம் நேராமல் இலக்கியங்களின் வழி மனித சமுதாயத்தைப் பாதுகாக்க வேண்டுமானால் மொழி என்னும் பயிருக்கு உரிமையான வேலி இன்றியமையாதது. சில உழவாந்கள் வேலியிலும் பீர்க்கு, பாகை, புடலை போன்ற உண்பதற்குரிய காய்களைத் தரும். கொடிகளைப் படரவிட்டுப் பயன்பெறுவார். அதைப்போலவே மொழிக்கு வேலியாகிய இலக்கணம் இரண்டு வகைப் பயன்களை வழங்குவதில் சிறப்புப் பெற்றவையாக அமைகின்றன.

ஓர் இலக்கியத்தைப் பயிலும் முன்பு எந்த வகை இன்பத்தில் ஒரு மாணவன் நுகர்கின்றானோ அதே வகை இன்பத்தை

பொருளடக்கம்

			பக்க எண்
1.	கிளவியாக்கம்	-	1
2.	வேற்றுமையியல்	-	14
3.	வேற்றுமை மயங்கியல்	-	18
4.	விளிமரபு	-	24
5.	பெயரியல்	-	33
6.	வினையியல்	-	41
7.	இடையியல்	-	55
8.	உரியியல்	-	69
9.	எச்சவியல்	-	85





முனைவர் மு.சுபாஷினி மணப்பாறை வட்டம் தொப்பம்பட்டி என்னும் கிராமத்தில் பிறந்தவர். போக்குவரத்து வசதி இல்லா ஊரில் இடைநிலைக் கல்விக்குமேல் தொடர்ந்து மேற்படிப்பைப் படித்த முதல் பெண்மணி ஆவார். எம்.ஏ.,பி.எட்., எம்ஃபில்., பிஜிடிசிஏ., பிஎச்.டி., ஆகிய பட்டங்களைப் பெற்றவர். எம்.ஏ., எம்ஃபில்., காட்டூர், உருமு தனலெட்சுமி கல்லூரியில் பயின்றவர். தஞ்சை, தமிழ்ப் பல்கலைக்கழகத்தில் ஆற்றுப்படை நூல்களில் அறிவியல் சிந்தனைகள் எனும் தலைப்பில் ஆய்வு செய்து முனைவர் பட்டம் பெற்றவர்.

முதுகலைப் பயிலும் போதே ஆராய்ச்சிக் கட்டுரை எழுதத் தொடங்கியவர். எழுபதுக்கும் மேற்பட்ட ஆய்வுக் கட்டுரைகளைப் பல்வேறு கல்லூரிகளுக்கு வழங்கியுள்ளார்.

கவியரசர் கலைத் தமிழ்ச் சங்கம் நடத்திய மாநில அளவிலான கட்டுரைப் போட்டியில் இலக்கியச் சுடர் விருது (2011), குறிஞ்சிக் கபிலர் தமிழ்ச் சங்கம் நடத்திய மாநில அளவிலான ஓவியப் போட்டியில் வரைகலை வளர்மணி விருது (2013), கொங்குநாடு கலை அறிவியல் கல்லூரி, கோவை, கதைத்தமிழ் ஆய்வு மாநாட்டிற்கு ஆய்வுக் கட்டுரை வழங்கியமைக்காகக் கதை ஆய்வுச்சுடர் விருது (2015), கவியரசர் கலைத் தமிழ்ச்சங்கம் பேராசிரியர் ரத்னா விருது (2018) ஆசிரியர் தின விழாவில் வழங்கியது.

பொருநை இலக்கியக் களம் மற்றும் சான்லாக்ஸ் பன்னாட்டுத் தமிழியல் ஆய்விதழ் நடத்திய பன்னாட்டுக் கருத்தரங்கிற்கு ஆய்வுக் கட்டுரை வழங்கியமைக்காகத் தமிழ் இலக்கிய வித்தகர் விருது (2019) பெற்றார். குறிஞ்சிக் கபிலர் தமிழ்ச் சங்கம் சேவைத் தொண்டினைப் பாராட்டி 70 வது குடியரசு தின விழாவில் சாதனைச் செம்மல் விருது (2019) பெற்றார்.

மாணவர்களை ஊக்கப்படுத்திக் கட்டுரை எழுத வைத்தமையைப் பாராட்டி சேவா ரத்னா விருது (2019) கவியரசர் கலைத் தமிழ்ச் சங்கம் வழங்கியது. உலகத் திருக்குறள் மாநாடு மலேசியா பல்கலைக்கழகத்திற்குக் கட்டுரை வழங்கியமைக்குப் பேராளர் நினைவுப் பரிசு (2019) பெற்றார். அனைத்திந்திய அறிவியல் தமிழ்க் கழகம் தஞ்சையில் நடத்திய 25 வெள்ளிவிழா கருத்தரங்கிற்கு ஆய்வுக் கட்டுரை வழங்கியமைக்காக நினைவுப் பேழை (2019) ஆகிய விருதுகளைப் பெற்றவர்.

PJAZYM PUBLICATIONS
No.1, Post Office Street
Khajamalai, Trichy - 23
Tamil Nadu
Mobile : 94435 87233
Email : jazymtrichy@gmail.com

ISBN 978-93-87360-51-8

Print @ The Printing House, Try-23. Ph:2420121


அன்றைய தமிழன்
சென்ற வழி
டாக்டர் ந. மாணிக்கம்

அன்றைய தமிழன் சென்ற வழி

முனைவர் **ந. மாணிக்கம்**

வெளியீடு

மலர்மகள் பதிப்பகம்

டி66, 8வது குறுக்குத்தெரு, (கிழக்கு)
தில்லை நகர்,
திருச்சிராப்பள்ளி - 18

நூற்குறிப்பு

நூற்பெயர்	:	**அன்றைய தமிழன் சென்ற வழி**
ஆசிரியர்	:	முனைவர் **ந. மாணிக்கம்**
மொழி	:	தமிழ்
பொருள்	:	திறனாய்வு
முதற் பதிப்பு	:	2020
உரிமை	:	ஆசிரியருக்கு
அளவு	:	டெம்மி
பக்கங்கள்	:	viii + 84 = 92
விலை	:	ரூ. 100/-
நூலாக்கம்	:	**"தி பிரிண்டிங்கு அவுசு"** காஜாமலை, திருச்சிராப்பள்ளி - 23. 0431-2420121
வெளியீடு	:	**மலர்மகள் பதிப்பகம்** டி66, 8வது குறுக்குத்தெரு, (கிழக்கு) தில்லை நகர், திருச்சிராப்பள்ளி - 18 செல் : 94435 31163
ISBN	:	ISBN 978-93-87360-69-3 9 789387 360693 >

❖❖❖



உழைப்பையே தெய்வமாகக் கருதும் உழவுக் குடும்பத்தில் பிறந்தவர். தந்தையார் நடேசன், தாயார் காமாட்சி இருவரையும் ஈன்றபொழுதின் பெரிதுவக்க வைத்தவர் முனைவர் ந. மாணிக்கம்.

ந. மாணிக்கம், முதுகலையிலிருந்து முனைவர் பட்டம் வரை திருச்சிராப்பள்ளியில் அமைந்துள்ள பாரம் பரியமிக்க தேசியக்கல்லூரியிலேயே பயின்று, அதே கல்லூரியில் தற்பொழுது இணைப்பேராசிரியராகப் பணியாற்றி வருபவர். மாணவர்கள் முதல் சான்றோர்கள் வரை அனைவரும் விரும்பத்தக்க பண்பாளர்.

மாணவர்களுக்கு இலக்கிய நன்னெறிகளைக் கற்பிக்கும் ஆசானாகவும், ஆய்வாளர்கள் பின்பற்றும் வழிகாட்டியாகவும் தன்னை வகுத்துக் கொண்டவர்.

வானம்பாடிக் கவிஞர் மு. மேத்தாவின் புதுக்கவிதைச் சாதனைகளைத் தனது ஆய்வின் வழித்தமிழுலகிற்கு உணர்த்தியவர். தேசியக்கல்லூரிப் பேராசிரியர் முழக்கம் ஆ. செகந்நாதன் அவர்களின் அன்பிற்குரிய மாணவர்.

5 நூல்களை வெளியிட்டுள்ளார். 60 ஆய்வுக்கட்டுரைகளை எழுதியுள்ளார். 80 இளமுனைவர் பட்ட மாணவர்களையும், 12 முனைவர்பட்ட மாணவர்களையும் தனது நெறிகாட்டுதலில் உருவாக்கியவர்.

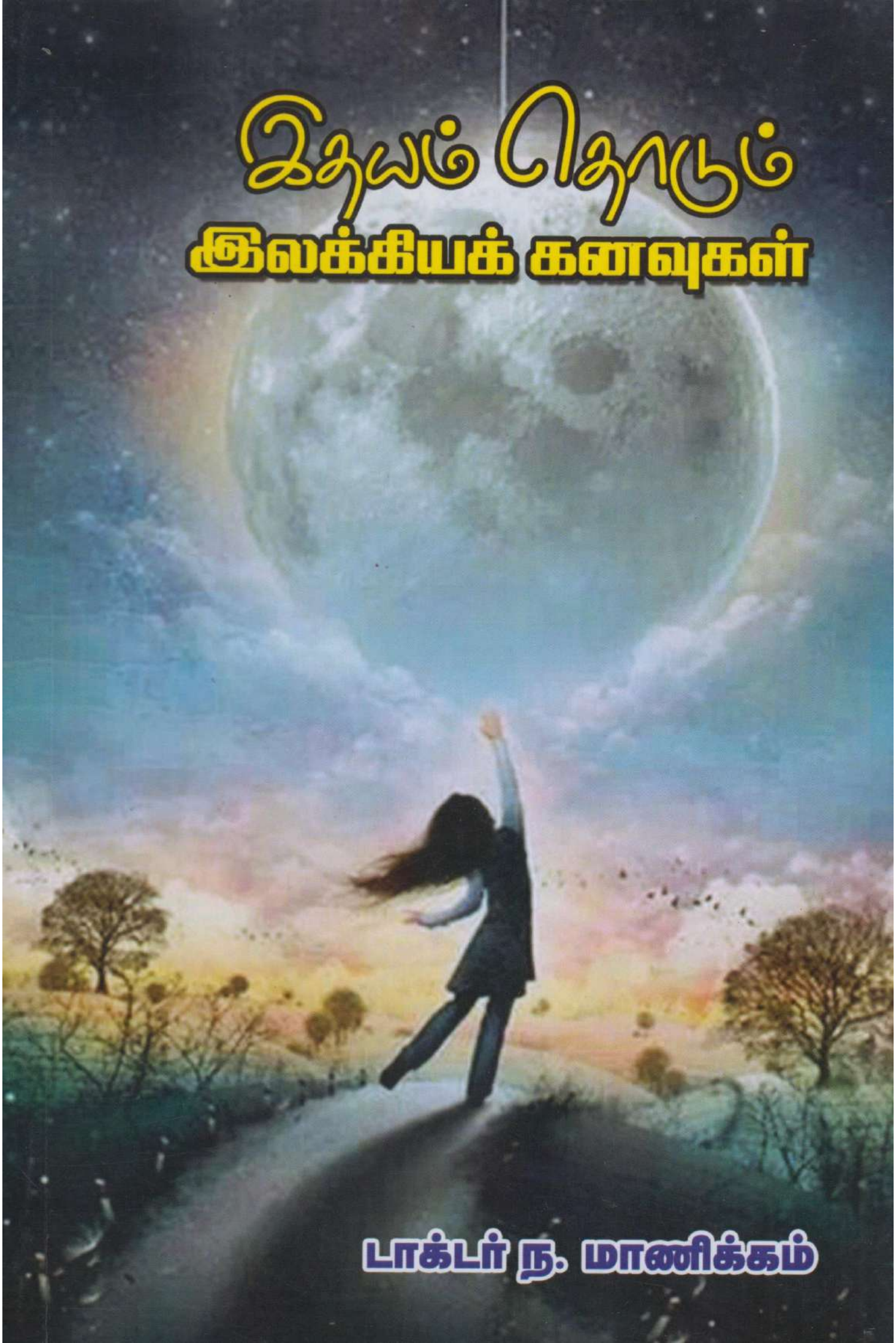
இலக்கியங்களில் பொதிந்து கிடக்கும் தகவல்களைக் கொங்குதேர் வாழ்க்கை அஞ்சிறைத் தும்பியாகக் கண்டறிந்து 600க்கும் மேற்பட்ட பட்டிமன்ற மேடைகளிலே பறைசாற்றி வந்துள்ளார்.

ISBN 978-93-87360-69-3

PJ JAZYM PUBLICATIONS
No.1, Post Office Street
Khajamalai, Trichy - 23, Tamil Nadu
Mobile : 94435 87233
Email : jazymtrichy@gmail.com

Print @ The Printing House, Try-23. Ph:2420121

இதயம் தொடும் இலக்கியக் கனவுகள்



டாக்டர் ந. மாணிக்கம்

இதயம் தொடும்

இலக்கியக் கனவுகள்

டாக்டர் **ந. மாணிக்கம்**

வெளியீடு

மலர்மகள் பதிப்பகம்

டி66, 8வது குறுக்குத்தெரு, (கிழக்கு)
தில்லை நகர்,
திருச்சிராப்பள்ளி - 18

நூற்குறிப்பு

நூற்பெயர்	:	**இதயம் தொடும் இலக்கியக் கனவுகள்**
ஆசிரியர்	:	முனைவர் **ந. மாணிக்கம்**
மொழி	:	தமிழ்
பொருள்	:	திறனாய்வு
முதற் பதிப்பு	:	2021
உரிமை	:	ஆசிரியருக்கு
அளவு	:	டெம்மி
பக்கங்கள்	:	(x) + 58 = 68
விலை	:	ரூ. 60/-
நூலாக்கம்	:	**"தி பிரிண்டிங்கு அவுசு"** காஜாமலை, திருச்சிராப்பள்ளி - 23. 0431-2420121
வெளியீடு	:	**மலர்மகள் பதிப்பகம்** டி66, 8வது குறுக்குத்தெரு, (கிழக்கு) தில்லை நகர், திருச்சிராப்பள்ளி - 18 செல் : 94435 31163
ISBN	:	978-93-91563-15-8

ISBN 978-93-91563-15-8

9 789391 563158



உழைப்பையே தெய்வமாகக் கருதும் உழவுக் குடும்பத்தில் பிறந்தவர். தந்தையார் நடேசன், தாயார் காமாட்சி இருவரையும் ஈன்றபொழுதின் பெரிதுவக்க வைத்தவர் முனைவர் ந. மாணிக்கம்.

ந. மாணிக்கம், முதுகலையிலிருந்து முனைவர் பட்டம் வரை திருச்சிராப்பள்ளியில் அமைந்துள்ள பாரம் பரியமிக்க தேசியக்கல்லூரியிலேயே பயின்று, அதே கல்லூரியில் தற்பொழுது இணைப்பேராசிரியராகப் பணியாற்றி வருபவர். மாணவர்கள் முதல் சான்றோர்கள் வரை அனைவரும் விரும்பத்தக்க பண்பாளர்.

மாணவர்களுக்கு இலக்கிய நன்னெறிகளைக் கற்பிக்கும் ஆசானாகவும், ஆய்வாளர்கள் பின்பற்றும் வழிகாட்டியாகவும் தன்னை வகுத்துக் கொண்டவர்.

வானம்பாடிக் கவிஞர் மு. மேத்தாவின் புதுக்கவிதைச் சாதனைகளைத் தனது ஆய்வின் வழித்தமிழுலகிற்கு உணர்த்தியவர். தேசியக்கல்லூரிப் பேராசிரியர் முழக்கம் ஆ. செகந்நாதன் அவர்களின் அன்பிற்குரிய மாணவர்.

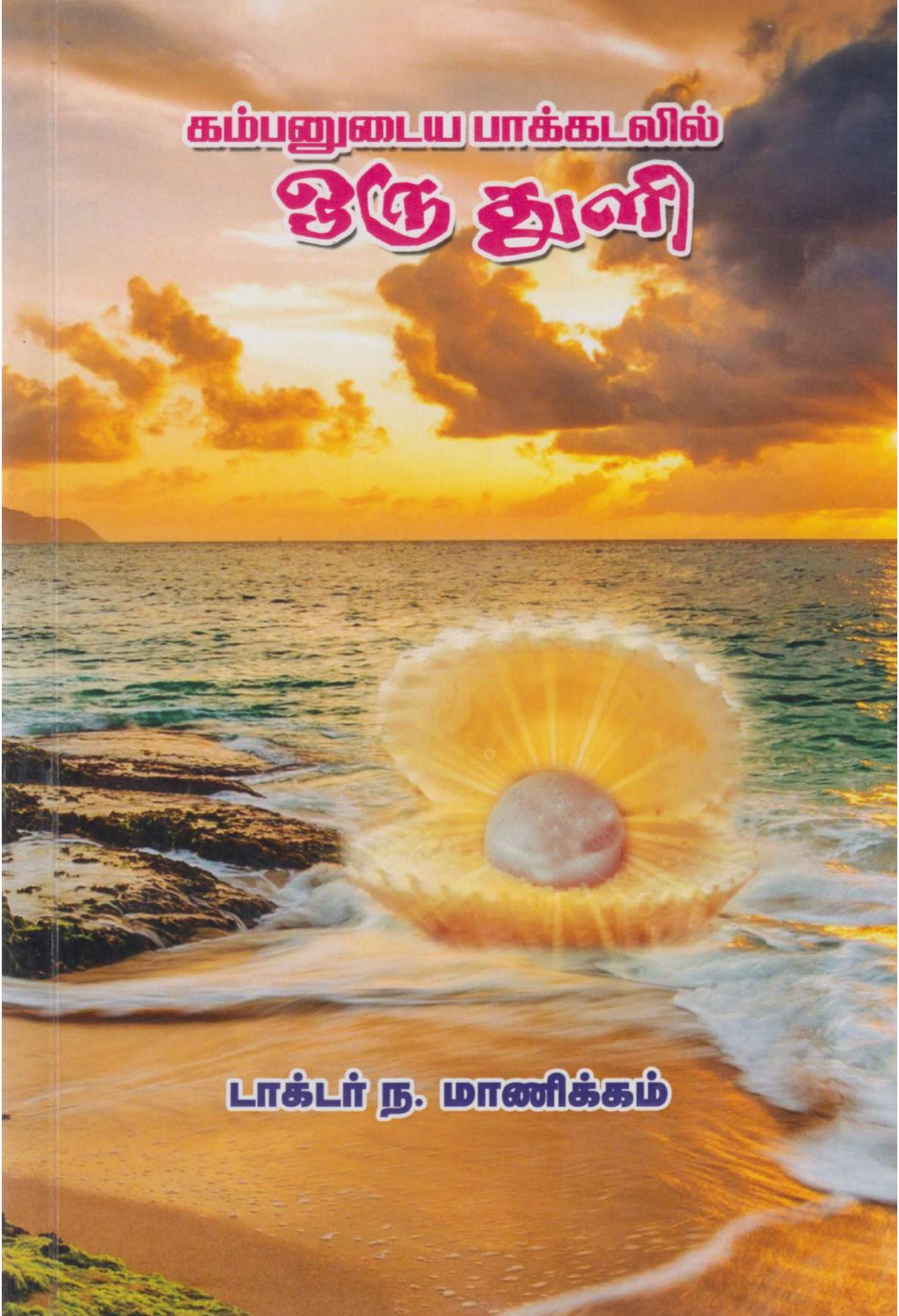
5 நூல்களை வெளியிட்டுள்ளார். 60 ஆய்வுக்கட்டுரைகளை எழுதியுள்ளார். 80 இளமுனைவர் பட்ட மாணவர்களையும், 12 முனைவர்பட்ட மாணவர்களையும் தனது நெறிகாட்டுதலில் உருவாக்கியவர்.

இலக்கியங்களில் பொதிந்து கிடக்கும் தகவல்களைக் கொங்குதேர் வாழ்க்கை அஞ்சிறைத் தும்பியாகக் கண்டறிந்து 600க்கும் மேற்பட்ட பட்டிமன்ற மேடைகளிலே பறைசாற்றி வந்துள்ளார்.

PJ JAZYM PUBLICATIONS
No.1, Post Office Street
Khajamalai, Trichy - 23, Tamil Nadu
Mobile : 94435 87233
Email : jazymtrichy@gmail.com

ISBN 978-93-91563-15-8
9 789391 563158

Print @ The Printing House, Try-23. Ph:2420121


கம்பனுடைய பாக்கடலில்
ஒரு துளி
டாக்டர் ந. மாணிக்கம்

கம்பனுடைய பாக்கடலில் ஒரு துளி

முனைவர் **ந. மாணிக்கம்**

வெளியீடு

மலர்மகள் பதிப்பகம்

டி66, 8வது குறுக்குத்தெரு, (கிழக்கு)
தில்லை நகர்,
திருச்சிராப்பள்ளி - 18

நூற்குறிப்பு

நூற்பெயர்	:	**கம்பனுடைய பாக்கடலில் ஒரு துளி**
ஆசிரியர்	:	முனைவர் **ந. மாணிக்கம்**
மொழி	:	தமிழ்
பொருள்	:	திறனாய்வு
முதற் பதிப்பு	:	2020
உரிமை	:	ஆசிரியருக்கு
அளவு	:	டெம்மி
பக்கங்கள்	:	viii + 80 = 88
விலை	:	ரூ. 100/-
நூலாக்கம்	:	**"தி பிரிண்டிங்கு அவுசு"** காஜாமலை, திருச்சிராப்பள்ளி - 23. 0431-2420121
வெளியீடு	:	**மலர்மகள் பதிப்பகம்** டி66, 8வது குறுக்குத்தெரு, (கிழக்கு) தில்லை நகர், திருச்சிராப்பள்ளி - 18 செல் : 94435 31163
ISBN	:	ISBN 978-93-87360-70-9 9 789387 360709 >

❖❖❖



உழைப்பையே தெய்வமாகக் கருதும் உழவுக் குடும்பத்தில் பிறந்தவர். தந்தையார் நடேசன், தாயார் காமாட்சி இருவரையும் ஈன்றபொழுதின் பெரிதுவக்க வைத்தவர் முனைவர் ந. மாணிக்கம்.

ந. மாணிக்கம், முதுகலையிலிருந்து முனைவர் பட்டம் வரை திருச்சிராப்பள்ளியில் அமைந்துள்ள பாரம் பரியமிக்க தேசியக்கல்லூரியிலேயே பயின்று, அதே கல்லூரியில் தற்பொழுது இணைப்பேராசிரியராகப் பணியாற்றி வருபவர். மாணவர்கள் முதல் சான்றோர்கள் வரை அனைவரும் விரும்பத்தக்க பண்பாளர்.

மாணவர்களுக்கு இலக்கிய நன்னெறிகளைக் கற்பிக்கும் ஆசானாகவும், ஆய்வாளர்கள் பின்பற்றும் வழிகாட்டியாகவும் தன்னை வகுத்துக் கொண்டவர்.

வானம்பாடிக் கவிஞர் மு. மேத்தாவின் புதுக்கவிதைச் சாதனைகளைத் தனது ஆய்வின் வழித்தமிழுலகிற்கு உணர்த்தியவர். தேசியக்கல்லூரிப் பேராசிரியர் முழக்கம் ஆ. செகந்நாதன் அவர்களின் அன்பிற்குரிய மாணவர்.

5 நூல்களை வெளியிட்டுள்ளார். 60 ஆய்வுக் கட்டுரைகளை எழுதியுள்ளார். 80 இளமுனைவர் பட்ட மாணவர்களையும், 12 முனைவர்பட்ட மாணவர்களையும் தனது நெறிகாட்டுதலில் உருவாக்கியவர்.

இலக்கியங்களில் பொதிந்து கிடக்கும் தகவல்களைக் கொங்குதேர் வாழ்க்கை அஞ்சிறைத் தும்பியாகக் கண்டறிந்து 600க்கும் மேற்பட்ட பட்டிமன்ற மேடைகளிலே பறைசாற்றி வந்துள்ளார்.

PJ JAZYM PUBLICATIONS
No.1, Post Office Street
Khajamalai, Trichy - 23
Tamil Nadu
Mobile : 94435 87233
Email : jazymtrichy@gmail.com

ISBN 978-93-87360-70-9
9 789387 360709 >

Print @ The Printing House, Try-23. Ph:2420121

A FIELD GUIDE TO THE

RAPTORS OF ASIA

SEDENTARY RAPTORS OF ORIENTAL AND EAST ASIA



A FIELD GUIDE TO THE

RAPTORS OF ASIA

SEDENTARY RAPTORS OF ORIENTAL AND EAST ASIA

VOLUME 2.



28.6 590
A-341
ISBN: 978-99978-3-126-2

Compiled by: **Gombobaatar Sundev and Toru Yamazaki**

Edited by: **Keith Bildstein**

Text written by: **Adam A. Supriatna, Anita Gamauf, Arthur W. Green, Asman Adi Purwanto, Camille Concepcion, Chaiyan Kasorndorkbua (co-author: Khoo Siew Yoong), Chien-hung Yang, Chien-wei Tseng, Dennis Salvador, Jan Ove Gjershaug, Gokula Varadharajan, Gombobaatar Sundev (co-authors: Bayanmunkh Dashnyam, Munkh-Erdene Jamsran, Odkhuu Biraazana, Richard Reading, Soronzonbold Ochirvaani and Usukhjargal Dorj), Hui-shan Lin, Kuang-Ying Huang, Le Manh Hung, Lim Aun Tiah, Lim Kim Chye (co-author: Chiu Sein Chiong), Marla Steele, Ming-Yuan Yang, Satish Pande (co-authors: Avishkar Munje, Niranjan Sant, Nivedita Pande, Pramod Deshpande, Rajkumar Pawar, Rajgopal Patil and Satish Karmalkar), Toru Yamazaki, Tulsi Subedi, Utku Perktas, Yuan-Hsun Sun, Yuka Chiba.**

Cover photographs: Niranjan Sant (Bonelli's Eagle), Yuan-Hsun Sun (Mountain Hawk Eagle) and Gombobaatar Sundev (Golden Eagle and Upland Buzzard).

Copyright © 2018. The first edition. Asian Raptor Research and Conservation Network. All rights reserved. No part of this book may be reproduced, stored in a retrieval system or transmitted in any form or by means electronic, mechanical, photocopying, recording or otherwise, without the prior written permission of the Asian Raptor Research and Conservation Network and authors.

Designed by: Asian Raptor Research and Conservation Network, Mongolica Publishing and Gombobaatar Sundev.

Suggested citation: Gombobaatar Sundev and Toru Yamazaki (compilers). 2018. *A Field Guide to the Raptors of Asia: Sedentary Raptors of Oriental and East Asia.* Vol.2. Asian Raptor Research and Conservation Network. 220 pp.

For the authors of species' text
Gamauf, A. 2018. Philippine Honey-buzzard (text). *A Field Guide to the Raptors of Asia. Sedentary Raptors of Oriental and East Asia.* Vol.2. (compilers Gombobaatar, S. & Yamazaki, T.). Asian Raptor Research and Conservation Network. p. 30-31.

Ministry of Environment,
Forest and Climate Change

सत्यमेव जयते

ZOOLOGICAL SURVEY
OF INDIA
1916

Faunal Diversity of
Biogeographic Zones:
Coasts of India

KAILASH CHANDRA | C. RAGHUNATHAN | TAMAL MONDAL

ZOOLOGICAL SURVEY OF INDIA

Faunal Diversity of Biogeographic Zones:
Coasts of India

CHANDRA
RAGHUNATHAN
MONDAL

ZOOLOGICAL SURVEY
OF INDIA
1916

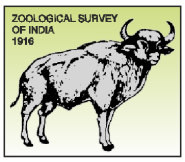
2020

Price
India : ₹ 5250/-
Foreign : $ 210; £ 160

9 788181 715432

Ministry of Environment, Forest and Climate Change

सत्यमेव जयते



Faunal Diversity of Biogeographic Zones: Coasts of India

KAILASH CHANDRA | C. RAGHUNATHAN | TAMAL MONDAL*

Zoological Survey of India, M-Block, New Alipore, Kolkata-700 053, West Bengal
**Zoological Survey of India, Andaman and Nicobar Regional Centre, Port Blair-744 102*

ZOOLOGICAL SURVEY OF INDIA
Ministry of Environment, Forest & Climate Change
Government of India

CITATION

Chandra, K., Raghunathan, C. and Mondal, T. 2020. *Faunal Diversity of Biogeographic Zones*: *Coasts of India* : 1-807. (Published by the Director, Zool. Surv. India, Kolkata).

Published : November, 2020

ISBN 978-81-8171-543-2

© *Govt. of India,* 2020

Disclaimer

It is hereby claimed that any views or opinions presented in the articles published in this book are solely those of the authors. The editors or the Zoological Survey of India have not independently verified the information gathered or contained in this book and, accordingly expressed no opinions or makes any representation concerning its accuracy or complete reliability or sufficiency. The ZSI disclaim any and all liability for, or based on or relating to any such information and/or contained in, or errors in or in omissions from, their inputs or information in this book. The ZSI will not accept any liability in respect of such communication, and the authors responsible will be personally liable for any damages or other liability arising.

Price
India : ₹ 5250/-
Foreign : $ 210; £ 160

Published at the Publication Division by the Director, Zoological Survey of India, M-Block, New Alipore, Kolkata-700 053 and printed at Calcutta Repro Graphics, Kolkata–700 006.

सी.के. मिश्रा
C.K. Mishra

सत्यमेव जयते

सचिव
भारत सरकार
पर्यावरण, वन एवं जलवायु परिवर्तन मंत्रालय
SECRETARY
GOVERNMENT OF INDIA
MINISTRY OF ENVIRONMENT, FOREST AND CLIMATE CHANGE



Foreword

The coast is a place where geosphere, ocean, biosphere, and atmosphere interact. Coastal areas comprise 20% of the Earth's surface, contains over 50% of the entire human population of the world with the density of 80 persons per square kilometre. Coastal ecosystem yields 90% of the global fisheries and harbours almost 80% of the fish species. The mangroves and coral reefs on the coast protect the shoreline by absorbing at least 70-90% of the energy of wind generated waves.

India accounts for less than 0.25 percent of the World's total castline i.e. 7516.6 km, however, about 63 million people live along the coasts which is approximately 11 percent of the coastal population of the globe. It is estimated that nearly 250 million people live within an area of 50 km from the coastline in India.

One of the ten biogeographic zones of India, Coasts play a vital role in nation's economy by virtue of their resources, rich biological diversity and productive habitats such as littoral mangroves forests, seagrass meadows, coral reef, creeks, deltaic plains, saline wetlands, tidal flats, mudflats, estuaries, gulf waters etc. In addition, harbours, aquaculture, agriculture, tourism and oil and mineral exploration associated with the marine environment account for approximately 10 percent of the country's GDP. The estimates of potential fishery resources from the EEZ of the country are between 3.5 and 4.7 million tonnes which lead India as 7th largest producer in terms of capture fisheries.

Coastal zones are continously changing because of the dynamic interactions between ocean and land. Erosion, accretion, inundation due to sea level rise and storm surge caused by natural and anthropogenic forces lead to changes in coastal zone and its environment. Hence the documentation of biodiversity is essential in the changing coastal morphology.

In order to understand the status of biodiversity in the coastal region of the country, Zoological Survey of India brought out the book on the Faunal Diversity of Biogeographic Zones: Coasts of India. The book covers all the faunal groups from Protozoa to Mammalia with their distributional details, and I am sure that this will serve as a benchmark data for the coastal and marine biodiversity in India for better conservation and sustainable utilization of biological resources.

I congratulate the authors for their efforts in bringing out this book meticulously for the benefit of policy makers, administrators, researchers and commons at larger extent to safeguard our biodiversity.

Date : March, 2020
Place : New Delhi

(C.K. Mishra)

इंदिरा पर्यावरण भवन, जोर बाग रोड़, नई दिल्ली-110 003 फोन : (011) 24695262, 24695265, फैक्स : (011) 24695270

INDIRA PARYAVARAN BHAWAN, JOR BAGH ROAD, NEW DELHI-110 003 Ph. : (011) 24695262, 2465265, Fax : (011) 24695270
E-mail : secy-moef@nic.in, Website : moef.gov.in

डॉ कैलाश चन्द्र
निदेशक
Dr Kailash Chandra
Director

सत्यमेव जयते

भारत सरकार
भारतीय प्राणि सर्वेक्षण
पर्यावरण, वन एवं जलवायु परिवर्तन मंत्रालय
Government of India
Zoological Survey of India
Ministry of Environment, Forest and Climate Change



Preface

Coasts are the transition zone between land and sea. Coastal ecosystems provide wide spectrum of goods and services in terms of biological, ecological as well as commercial aspects. The geomorphology of Indian coastal areas is featured by 43% sandy, 36% muddy, 11% rocky and 10% marshy beaches. Amidst the variety of habitats along with latitudinal and longitudinal differentiation, the faunal communities of the coastal region encompass vivid scale of assortment which is required to be documented to ensure comprehensive species database of Indian coastal regions.

The generation of species database not only to understand the biodiversity but also fulfil the need of achieving international framework for the conservation of biodiversity and sustainable development under Convention on Biological Diversity (CBD). As the coastline of the world facing tremendous pressure of alteration during the recent time with greater ratio, the species inhabited on the coasts facing massive threats towards decline.

Coastal and marine ecosystems provide a broad range of ecosystem goods and services to human society, because they are one of the most productive ecosystems on Earth. Recently, most services provided by the oceans and coastal zones have more rapidly deteriorated than other ecosystems due to high population densities but also to development pressures in the coastal zone. In India, about 34% of coastline is under varying degree of coastal erosion, 28% is of accreting nature condition and the remaining 38% falls stable state along 66 districts in 10 maritime States and UTs.

Given this scenario, Zoological Survey of India brought out the book on the Faunal Diversity of Biogeographic Zones: Coasts of India comprising 61 chapters and covering 54 major faunal groups from lower to higher taxon. The book depicts the distribution of 12756 species of biota including 11,181 species on animals, 702 species of protozoans and 873 species of flora in Indian coast. The book is a first-of-its-kind attempt by collating all the information available on the coastal biodiversity and it will serve as a tool for biodiversity conservation in Indian context especially in coastal belt.

I strongly believe that the consolidated information on the faunal diversity of coasts produced in the book will be useful for managing the faunal resources of maritime states for effective conservation and sustainable utilization.

(Kailash Chandra)

Kolkata
12th March 2020

ZOOLOGICAL SURVEY OF INDIA 1916

प्राणि विज्ञान भवन, 535, एम. ब्लॉक, न्यु अलीपुर, कोलकाता – 700 053, दूरभाष : +91 33 2400 6893, टेलीफैक्स : +91 33 2400 8595
Prani Vigyan Bhawan, 535, M-Block, New Alipore, Kolkata - 700 053, Phone : +91 33 2400 6893, Telefax : +91 33 2400 8595
E-mail : kailash611@rediffmail.com, Website : zsi.gov.in

Contents

Chapter 1
Faunal Diversity of Biogeographic Zones: Coasts of India - An Overview 1-12
Kailash Chandra, C. Raghunathan and *Tamal Mondal*

Chapter 2
Protozoa : Ciliata (Free-Living) 13-30
Daizy Bharti, Santosh Kumar and *Kailash Chandra*

Chapter 3
Foraminifera 31-51
Jhimli Mondal, Tamal Mondal and *C. Raghunathan*

Chapter 4
Mesozoa : Dicyemida 53-56
Jhimli Mondal and *C. Raghunathan*

Chapter 5
Porifera 57-82
Preeti Pereira and *C. Raghunathan*

Chapter 6
Cnidaria (Scleractinian corals) 83-111
Tamal Mondal

Chapter 7
Cnidaria (Octocorals) 113-128
Seepana Rajendra, J.S. Yogesh Kumar and *C. Raghunathan*

Chapter 8
Cnidaria : Hydrozoa 129-145
Oishinee Chakraborty and *C. Raghunathan*

Chapter 9
Cnidaria : Actiniaria 147-158
Smitanjali Choudhury and *C. Raghunathan*

Chapter 10
Cnidaria : Scyphozoa 159-167
Smitanjali Choudhury and *C. Raghunathan*

Chapter 11
Cnidaria : Cubozoa 169-171
J.S. Yogesh Kumar

Chapter 12
Ctenophora 173-176
J.S. Yogesh Kumar

Chapter 13
Platyhelminthes 177-200
Oishinee Chakraborty, Tamal Mondal and *C. Raghunathan*

Chapter 14
Platyhelminthes (Polyclads) 201-204
Sudhanshu Dixit, C. Raghunathan and *Tamal Mondal*

Chapter 15
Rotifera
Chitra, J. 205-218

Chapter 16
Gastrotricha 219-223
Tamal Mondal and *C. Raghunathan*

Chapter 17
Gnathostomulida 225-226
Chitra J.

Chapter 18
Kinorhyncha 227-230
Oishinee Chakraborty, Tamal Mondal and *C. Raghunathan*

Chapter 19
Nematoda 231-254
Pallab Maity, Seepana Rajendra, Punyasloke Bhadury and *Anjum N. Rizvi*

Chapter 20
Sipuncula 255-259
C. Raghunathan and *Jhimli Mondal*

Chapter 21
Echiura 261-264
J.S. Yogesh Kumar

Chapter 22
Annelida : Archianellida 265-268
S. Balakrishnan

Chapter 23
Annelida : Polychaeta 269-300
S. Balakrishnan

Chapter 24
Arthropoda : Pycnogonida 301-307
Md. Nurul Hasan and *N. Marimuthu*

Chapter 25
Arthropoda : Merostomata 309-312
Anil Mohapatra

Chapter 26
Arthropoda : Crustacea : Thoracica 313-320
Prasad Chandra Tudu

Chapter 27
Arthropoda : Crustacea : Branchiura 321-323
K. Valarmathi

Chapter 28
Arthropoda : Crustacea : Copepoda 325-331
Honey U.K. Pillai and *Biju A.*

Chapter 29
Arthropoda : Crustacea : Ostracoda 333-345
Jasmine Purushothaman, Alfisa Siddique and *C. Raghunathan*

Chapter 30
Arthropoda : Crustacea : Stomatopoda 347-354
N. Marimuthu, Panakkool Thamban Aneesh and *K. Paramasivam*

Chapter 31
Arthropoda : Crustacea : Mysida 355-358
Biju A and *Honey U.K. Pillai*

Chapter 32
Arthropoda : Crustacea : Amphipoda 359-374
Alfisa Siddique, Jasmine Purushothaman and *C. Raghunathan*

Chapter 33
Arthropoda : Crustacea : Tanaidacea 375-378
R.S. Pandiyarajan and *R. Jyothibabu*

Chapter 34
Arthropoda : Crustacea : Cumacea 379-382
Biju A. and *Honey U.K. Pillai*

Chapter 35
Arthropoda : Crustacea : Decapoda (Shrimps/Prawns, Mudshrimps and Crayfish) 383-400
K. Valarmathi

Chapter 36
Arthropoda : Crustacea : Decapoda (Lobsters) 401-406
Prasad Chandra Tudu

Chapter 37
Arthropoda : Crustacea : Anomura 407-418
S.K. Pati

Chapter 38
Arthropoda : Crustacea : Brachyura 419-458
K. Valarmathi

Chapter 39
Arthropoda : Insecta : *Halobates* – Sea Skaters 459-461
Amos Shem Samuel, Swetapadma Dash and *A. Rameshkumar*

Chapter 40
Phoronida 463-465
J.S. Yogesh Kumar

Chapter 41
Bryozoa 467-478
C. Venkatraman and *C. Raghunathan*

Chapter 42
Entoprocta 479-481
S. Balakrishnan

Chapter 43
Brachiopoda 483-485
C. Raghunathan and *Tamal Mondal*

Chapter 44
Chaetognatha 487-491
Naveen Kumar Nigam and *Tamal Mondal*

Chapter 45
Tardigrada 493-495
Chemmencheri Ramakrishnan Sreeraj

Chapter 46
Mollusca 497-574
Seepana Rajendra and *C. Raghunathan*

Chapter 47
Mollusca : Heterobranchia 575-594
Chemmencheri Ramakrishnan Sreeraj

Chapter 48
Mollusca : Heterobranchia : Pteropoda 595-602
Aishee Bhowal and *Jasmine Purushothaman*

Chapter 49
Nemertea 603-606
Chemmencheri Ramakrishnan Sreeraj

Chapter 50
Echinodermata 607-632
Naveen Kumar Nigam and *C. Raghunathan*

Chapter 51
Hemichordata 633-638
Jhimli Mondal and *Tamal Mondal*

Chapter 52
Chordata : Cephalochoradata 639-641
Prasad Chandra Tudu

Chapter 53
Chordata : Tunicata : Ascidiacea 643-654
Jhimli Mondal, Tamal Mondal and *C. Raghunathan*

Chapter 54
Pisces 655-722
Anil Mohapatra, Subhrendu Sekhar Mishra, Bineesh K.K., Seepana Rajendra, Dipanjan Ray, Swarup Ranjan Mohanty and *Sanmitra Roy*

Chapter 55
Reptilia 723-728
Kailash Chandra and *C. Raghunathan*

Chapter 56
Aves 729-742
C. Venkatraman, V. Gokula and *C. Sivaperuman*

Chapter 57
Marine Mammals 743-748
C. Raghunathan and *Kailash Chandra*

Chapter 58
Marine Macro Algae 749-783
M. Palanisamy and *Aron Santhosh Kumar Y.*

Chapter 59
Seagrasses 785-788
Kailash Chandra, C. Raghunathan and *Tamal Mondal*

Chapter 60
Mangroves 789-796
K. Kathiresan

Chapter 61
Threats and Mitigations 797-807
Kailash Chandra, C. Raghunathan and *Tamal Mondal*



Contributors

1. **Kailash Chandra**
   Zoological Survey of India, M-Block, New Alipore, Kolkata–700 053, West Bengal
2. **C. Raghunathan**
   Zoological Survey of India, M-Block, New Alipore, Kolkata–700 053, West Bengal
3. **C. Sivaperuman**
   Zoological Survey of India, Andaman and Nicobar Regional Centre, Port Blair–744 102, Andaman and Nicobar Islands
4. **C. Venkatraman**
   Zoological Survey of India, M-Block, New Alipore, Kolkata–700 053, West Bengal
5. **Anil Mohapatra**
   Zoological Survey of India, Estuarine Biology Regional Centre, Gopalpur-on-Sea, Ganjam-761 002, Odisha
6. **Swetapadma Dash**
   Zoological Survey of India, M-Block, New Alipore, Kolkata–700 053, West Bengal
7. **Anjum N. Rizvi**
   Zoological Survey of India, M-Block, New Alipore, Kolkata–700 053, West Bengal
8. **Jasmine Purushothaman**
   Zoological Survey of India, M-Block, New Alipore, Kolkata–700 053, West Bengal
9. **K. Valarmathi**
   Zoological Survey of India, FPS Building, Indian Museum complex, Kolkata-700 016, West Bengal
10. **J.S. Yogesh Kumar**
    Zoological Survey of India, Marine Aquarium and Regional Centre, Digha–721 428, West Bengal
11. **S. Balakrishnan**
    Zoological Survey of India, Marine and Aquarium Regional Centre, Digha–721 428, West Bengal
12. **N. Marimuthu**
    Zoological Survey of India, FPS Building, Indian Museum Complex, Kolkata-700 016, West Bengal
13. **Honey U.K. Pillai**
    Zoological Survey of India, M-Block, New Alipore, Kolkata–700 053, West Bengal
14. **Bineesh, K.K.**
    Zoological Survey of India, Andaman and Nicobar Regional Centre, Port Blair–744 102, Andaman and Nicobar Islands
15. **Santosh Kumar**
    Zoological Survey of India, M-Block, New Alipore, Kolkata–700 053, West Bengal
16. **Subhrendu Sekhar Mishra**
    Zoological Survey of India, Marine Fish Section, Kolkata-700 016, West Bengal
17. **Tamal Mondal**
    Zoological Survey of India, Andaman and Nicobar Regional Centre, Port Blair–744 102, Andaman and Nicobar Islands
18. **Chitra, J.**
    Zoological Survey of India, M-Block, New Alipore, Kolkata–700 053, West Bengal
19. **A. Rameshkumar**
    Zoological Survey of India, M-Block, New Alipore, Kolkata–700 053, West Bengal
20. **Chemmencheri Ramakrishnan Sreeraj**
    Zoological Survey of India, Sunderban Regional Centre, Canning-743 329, West Bengal
21. **Prasad C. Tudu**
    Zoological Survey of India, Marine and Aquarium Regional Centre, Digha–721 428, West Bengal
22. **S.K. Pati**
    Zoological Survey of India, Western Regional Centre, Pune-411 044, Maharashtra
23. **Jhimli Mondal**
    Centre for Marine Living Resources and Ecology, Kendriya Bhavan, Block–C, Kakkanad, Kochi-682 037, Kerala
24. **Smitanjali Choudhury**
    Zoological Survey of India, Andaman and Nicobar Regional Centre, Port Blair–744 102, Andaman and Nicobar Islands

25. **Sudhanshu Dixit**
Centre for Marine Living Resources and Ecology, Kendriya Bhavan, Block–C, Kakkanad, Kochi-682 037, Kerala

26. **Seepana Rajendra**
Zoological Survey of India, Andaman and Nicobar Regional Centre, Port Blair–744 102, Andaman and Nicobar Islands

27. **Naveen Kumar Nigam**
Zoological Survey of India, Andaman and Nicobar Regional Centre, Port Blair–744 102, Andaman and Nicobar Islands

28. **Preeti Pereira**
Zoological Survey of India, Andaman and Nicobar Regional Centre, Port Blair–744 102, Andaman and Nicobar Islands

29. **Oishinee Chakraborty**
Zoological Survey of India, Andaman and Nicobar Regional Centre, Port Blair–744 102, Andaman and Nicobar Islands

30. **Daizy Bharti**
Zoological Survey of India, M-Block, New Alipore, Kolkata–700 053, West Bengal

31. **Pallab Maity**
Zoological Survey of India, M-Block, New Alipore, Kolkata–700 053, West Bengal

32. **Alfisa Siddique**
Zoological Survey of India, M-Block, New Alipore, Kolkata–700 053, West Bengal

33. **Aishee Bhowal**
Zoological Survey of India, M-Block, New Alipore, Kolkata–700 053, West Bengal

34. **Panakkool Thamban Aneesh**
Zoological Survey of India, M-Block, New Alipore, Kolkata–700 053, West Bengal

35. **Amos Shem Samuel**
Zoological Survey of India, M-Block, New Alipore, Kolkata–700 053, West Bengal

36. **K. Paramasivam**
Zoological Survey of India, Marine Biology Regional Centre, 130, Santhome High Road, Chennai-600 028, Tamil Nadu

37. **Md. Nurul Hasan**
Zoological Survey of India, FPS Building, Indian Museum Complex, Kolkata-700 016, West Bengal

38. **Swarup Ranjan Mohanty**
Zoological Survey of India, Estuarine Biology Regional Centre, Gopalpur-on-Sea, Ganjam-761 002, Odisha

39. **Sanmitra Roy**
Zoological Survey of India, Estuarine Biology Regional Centre, Gopalpur-on-Sea, Ganjam-761 002, Odisha

40. **K. Kathiresan**
UGC-BSR Faculty Fellow & Honorary Professor, Centre of Advanced Study in Marine Biology, Faculty of Marine Sciences, Annamalai University, Parangipettai-608 502, Tamil Nadu

41. **M. Palanaisamy**
Botanical Survey of India, Southern Regional Centre, TNAU Campus, Coimbatore–03

42. **Dipanjan Ray**
Bajkul Milani Mahavidyalaya, Kismat Bajkul, Purba Medinipur-721 655, West Bengal

43. **Punyasloke Bhadury**
Integrative Taxonomy and Microbial Ecology Research, Department of Biological Sciences & Centre for Climate and Environmental Studies, Indian Institute of Science Education and Research Kolkata, Mohanpur-741 246, Nadia, West Bengal

44. **Biju A.**
Zoology Research Centre, St. Stephens College, Pathanapuram, University of Kerala, Kollam–689 695, Kerala

45. **R.S. Pandiyarajan**
CSIR- National Institute of Oceanography, Regional Centre – Kochi- 628 017, Kerala

46. **R. Jyothibabu**
CSIR- National Institute of Oceanography, Regional Centre – Kochi-628 017, Kerala

47. **Aron Santhosh Kumar Y.**
Botanical Survey of India, Southern Regional Centre, TNAU Campus, Coimbatore – 03

48. **V. Gokula**
Department of Zoology, National College, Tiruchirappalli-620 001, Tamil Nadu

Chapter 56

Aves

[1]C. VENKATRAMAN, [2]V. GOKULA and [3]C. SIVAPERUMAN



INTRODUCTION

Birds play a significant role in human lives culturally, socially, scientifically and as a food resource. Hence, birds attract people to various environments that birds inhabit. In general, birds are classified as terrestrial and waterbirds. Terrestrial birds refer to bird species that prefers largely woodland and occasionally use the wetlands in search of food, shelter and loaf. Waterbird refers to bird species that entirely depend on wetlands for variety of activities such as foraging, nesting, loafing and moulting (Rajpar and Zakaria, 2009). Waterbirds include waterfowl, waders and seabirds. Besides, some species of raptors, kingfishers and passerines are also included in this group (Kumar et al 2003). About nine of 156 existing families of birds are rather specialized as seabirds: the Speniscidae (penquins), Diomedeidae (albatrosses), Procellariidae (petrels), Hydrobatidae (storm-petrels), Pelecanoididae (diving petrels), Phathontidae (tropicbirds), Sulidae (Boobies) Fregatidae (frigatebirds), Alcidae (auks), and a few species (terns) of Laridae (gulls and terns) (Ainley, 1980). Inspite of not being confined to the water as fish and marine mammals, the members of the above mentioned families derive all their food from the sea, participate in the marine energy cycles and thus should be recognized as true marine organisms. Besides, it is also calculated that a typical seabird spends about 85% of its time annually at sea during its breeding years; over its entire lifetime, it spends 90% of its time at sea (Ainley, 1978). However, bird species from 15 other families, principally the Gaviidae (loons), Podicipedidae (grebes), Pelecanidae (pelicans), Phalacrocoracidae (cormorants), Anatida: (ducks and geese), Scolopacidae (shorebirds), Stercorariidae (skuas), Rynchopidae (skimmers), and the majority of the Laridae that, undertake even a small part of their life cycle at sea are also considered to be "seabirds." Except the breeding behaviour and biology of seabirds, little or nothing about seabirds is known (Sanger, 1972 and Ainley and Sanger, 1979). Similarly, coastal zones are one of the neglected habitats around the world. Like anyother country, both coastal birds and coastal habitats are poorly explored in India, despite fabulous congregations of birds seen in Chilika Lake and Bhitarkanika in Orissa, Point Calimere Wildlife Sanctuary in Tamil Nadu, Sunderbans in West Bengal, Sewri mudflats in Maharashtra, and Kori Creek in Gujarat. The migratory coastal birds, at both global and local scales, are considered as environmental indicators as they connect continents and countries. Hence, an attempt is made to comprehensively document the diversity of avifauna in the coastal biogeographic zone, India.

METHODS

The present study is based on the field studies conducted by the authors in the coastal biogeography zone (Sivaperuman and Jayson, 2000, 2009; Jayson and Sivaperuman, 2003, 2004, 2005; Sivaperuman, 2011, 2013; Sivaperuman *et al.*, 2010; Venkataraman, 2008; Venkatraman and Gokula 2009). Besides, other studies related to birds of coastal zones are also discussed (Sampath, 1989; Sampath and Krishnamurthy, 1989; Balachandran, 1990, 1995, 1998, 2006; Kurup, 1991, 1996; Anon. 1992, 1993; Venkatraman and Muthukrishnan, 1993; Jayson and Easa, 2000; Acharya and Kar 1996; Nagarajan and Thiyagesan 1996; Oswin, 1999; Verma *et al.*, 2002; Biju Kumar, 2006; Gopi and Pandav, 2007; Pawar, 2011; Kannan and Pandiyan, 2012; Ramamurthy and Rajakumar, 2014; Jisha Kurian, 2014). Ali and Ripley (1983) was followed for the classification of migratory or resident species while Manakadan and Pittie (2001) was followed for the common and scientific names of birds.

RESULTS AND DISCUSSION

Two hundred and twenty-four species of birds belonging to 32 families under nine orders were recorded from the coastal biogeographic zone of India (Table 1). The East

[1]Zoological Survey of India, M-Block, New Alipore, Kolkata-744 102, West Bengal
[2]Department of Zoology, National College, Tiruchirappalli-620 001, Tamil Nadu
[3]Zoological Survey of India, Andaman and Nicobar Regional Centre, Haddo, Port Blair-744 102, Andaman and Nicobar Islands
Email: cvramanmbs@yahoo.com; gokulae@yahoo.com; c_sivaperuman1@rediffmail.com

Citation
Venkatraman, C. Gokula, V. and Sivaperuman, C. 2020. Aves. In: *Faunal Diversity of Biogeographic Zones* : *Coasts of India* : 729-742. (Published by the Director, Zool. Surv. India, Kolkata)



coast alone harbours 165 species of birds belonging to 24 families under eight orders while the West coast harbours 166 species of birds belonging to 26 families under eight orders. The Lakshadweep attracts 98 species of birds belonging to 23 families under eight orders. Greater number of species belongs to the order Charadriformes followed by the orders Falconiformes and Ciconiiformes. A comparison of number of bird species recorded with those from the Indian subcontinent as a whole and worldwide is given in Table (2).

Table 1: Birds of Coasts of India

Sl. No.	Common Name	Species name	Status	East Coast	West Coast	Lakshadweep
	Podicipediformes PODICIPEDIDAE					
1	Little Grebe	*Tachybaptus ruficollis* (Pallas, 1764)	R, LC	•	•	
2	Great Crested Grebe	*Podiceps cristatus* (Linnaeus, 1758)	M, LC		•	
	Procellariiformes PROCELLARIIDAE					
3	Barau's Petrel	*Pterodroma baraui* (Jouanin, 1964)	M, LC			•
4	Jouanin's Petrel	*Bulweria fallax* Jouanin, 1955	M, LC			•
5	Wedge-tailed Shearwater	*Puffinus pacificus* (Gmelin, 1789)	M, LC			•
6	Flesh-footed Shearwater	*Puffiinus carneipes* Gould, 1844	M, LC			•
	HYDROBATIDAE					
7	Wilson's Storm- Petrel	*Oceanites oceanicus* (Kuhl, 1820)	M, LC			•
8	Black-bellied Storm-Petrel	*Fregetta tropica* (Gould, 1844)	M, LC			•
9	Swinhoe's Storm- Petrel	*Oceanotoma monorhis* (Swinhoe, 1867)	M, LC			•
	Pelecaniformes PHAETHONTIDAE					
10	Grey-backed Tropicbird	*Phaethon aethereus* Linnaeus, 1758	M, LC			•
11	Yellow-billed Tropicbird	*Phaethon lepturus* Daudin, 1802	R, LC			•
	PELECANIDAE					
12	Great White pelican	*Pelecanus onocrotalus* Linnaeus, 1758	RM, LC		•	•
13	Spot-billed Pelican	*Pelecanus philippensis* Gmelin, 1759	RM, NT	•	•	
14	Dalmatian Pelican	*Pelecanus crispus* Bruch, 1832	M, VU		•	
	SULIDAE					
15	Masked Booby	*Sula dactylatra* Lesson, 1831	R, LC		•	•
16	Brown Booby	*Sula leucogaster* (Boddaert, 1783)	R, LC			•
	PHALACROCORACIDAE					
17	Little Cormorant	*Phalacrocorax niger* (Vieillot, 1817)	R, LC	•	•	
18	Great Cormorant	*Phalacrocorax carpo* (Linnaeus, 1758)	R, LC	•	•	•
19	Indian Shag	*Phalacrocorax fuscicollis* Stephens, 1826	R, LC	•	•	
	ANHINGIDAE					
20	Darter	*Anhinga melanogaster* Pennant, 1769	R, NT	•	•	
	FREGATIDAE					
21	Lesser Frigatebird	*Fregata ariel* (G.R. Gray, 1845)	M, LC	•	•	•
22	Greater Frigatebird	*Fregata minor* (Gmelin, 1789)	M, LC			•



Table 1 contd.

Sl. No.	Common Name	Species name	Status	East Coast	West Coast	Lakshadweep
	Ciconiiformes ARDEIDAE					
23	Little Egret	*Egretta garzetta* (Linnaeus, 1766)	R, LC	•	•	•
24	Western Reef Egret	*Egretta gularis* ((Bosc, 1792)	RM, LC	•	•	•
25	Pacific Reef- Egret	*Egretta sacra* (Gmelin,1789)	RM, LC	•		
26	Grey Heron	*Ardea cinerea* Linnaeus, 1758	RM, LC	•	•	•
27	Goliath Heron	*Ardea goliath* Cretzschmar, 1829	V, LC	•		
28	Purple Heron	*Ardea purpurea* Linnaeus, 1766	RM, LC	•	•	•
29	Great Egret	*Egretta alba* (Linnaeus, 1758)	RM, LC			•
30	Intermediate Egret	*Egretta intermedia* (Wagler, 1829)	RM, LC			•
31	Large Egret	*Casmerodius albus* Linnaeus, 1758	RM, LC	•	•	
32	Median Egret	*Mesophoyx intermedia* (Wagler, 1829)	RM, LC	•	•	
33	Eastern Cattle Egret	*Bubulcus coromandus* (Boddaert, 1783)	RM, LC			•
34	Cattle Egret	*Bubulcus ibis* (Linnaeus, 1758)	RM, LC	•	•	•
35	Chinese Egret	*Egretta eulophotes* (Swinhoe, 1860)	RM, LC			•
36	Indian Pond Heron	*Ardeola grayii* (Sykes, 1832)	R, LC	•	•	•
37	Chinese Pond-Heron	*Ardeola bacchus* (Bonaparte, 1855)	RM, LC	•		•
38	Little Green Heron	*Butroides striatus* (Linnaeus, 1758)	R, NR	•	•	•
39	Black-crowned Night-Heron	*Nycticorax nycticorax* (Linnaeus, 1758)	R, LC	•	•	•
40	Yellow Bittern	*Ixobrychus sinensis* (Gmelin, 1789)	RM, LC	•	•	•
41	Chestnut Bittern	*Ixobrychus cinnamomeus* (Gmelin, 1789)	RM, LC	•	•	•
42	Black Bittern	*Dupetor flavicollis* (Latham, 1790)	RM, LC	•	•	•
43	Great Bittern	*Botaurus stellaris* (Linnaeus, 1758)	M, LC	•		
	CICONIIDAE					
44	Painted Stork	*Mycteria leucocephala* (Pennant, 1769)	R, NT	•	•	
45	Asian Openbill-Stork	*Anastomus osciatans* (Boddaert, 1783)	R, LC	•	•	
46	Black Stork	*Ciconia nigra* (Linnaeus, 1758)	M, LC		•	
47	White-necked Strok	*Ciconia epscopus* (Boddaert, 1783)	R, LC		•	•
48	European White Stork	*Ciconia ciconia* (Linnaeus, 1758)	M, LC	•	•	
49	Black-necked Stork	*Ephippiorhyncus asiaticus* (Latham, 1790)	R, NT	•	•	
50	Lesser Adjutant Stork	*Leptoptilys javanicus* (Horsfield, 1821)	R, VU	•		
	THRESKIORNITHIDAE					
51	Glossy Ibis	*Plegadis falcinellus* (Linnaeus, 1766)	R, LC	•	•	•
52	Oriental White Ibis	*Threskiornis melanocephalus* (Latham, 1790)	R, LC	•	•	
53	Black Ibis	*Pseudibis papillosa* (Temminck, 1824)	R, LC	•	•	
54	Eurasian Spoonbill	*Platalea leucorodia* Linnaeus, 1758	R, LC	•	•	•
	Phoenicopteriformes PHOENICOPTERIDAE					
55	Greater Flamingo	*Phoenicopterus ruber* Linnaeus, 1758	R, LC	•	•	



Table 1 contd.

Sl. No.	Common Name	Species name	Status	East Coast	West Coast	Lakshadweep
56	Lesser Flamingo	*Pheonicopterus minor* (Geoffroy, 1798)	R, NT	•	•	•
	Anseriformes ANATIDAE					
57	Large Whistling-Duck	*Dendrocygna bicolor* (Vieillot, 1816)	R, LC	•		
58	Lesser Whistling-Duck	*Dendrocygna javanica* (Horsfield, 1821)	R, LC	•	•	
59	Greylag Goose	*Anser anser* (Linnaeus, 1758)	R, LC		•	
60	Bar-headed Goose	*Anser indicus* (Latham, 1790)	R, LC	•		
61	Brahminy Shelduck	*Tadorna ferruginea* (Pallas, 1764)	R, LC	•	•	•
62	Comb Duck	*Sarkidiornis melanotus* (Pennant, 1769)	R, LC	•	•	
63	Cotton Teal	*Nettapus coromandelianus* (Gmelin, 1789)	R, LC	•	•	
64	Gadwall	*Anas strepera* Linnaeus, 1758	M, LC	•	•	
65	Eurasian Wigeon	*Anas penelope* Linnaeus, 1758	M, LC	•	•	
66	Mallard	*Anas platyrhynchos* Linnaeus, 1758	RM, LC	•	•	
67	Spot- billed Duck	*Anas poecilorhyncha* J.R. Forester, 1781	R, LC	•	•	
68	Northern Shoveller	*Anas clypeata* Linnaeus, 1758	M, LC	•	•	
69	Northern Pintail	*Anas acuta* Linnaeus, 1758	M, LC	•	•	
70	Garganey	*Anas querquedula* Linnaeus, 1758	M, LC	•	•	
71	Common Teal	*Anas crecca* Linnaeus, 1758	M, LC	•	•	•
72	Red-crested Pochard	*Rhodonessa rufina* (Pallas, 1773)	M, LC	•		
73	Common Pochard	*Aythya ferina* (Linnaeus, 1758)	M, LC	•	•	
74	Ferruginous Pochard	*Aythya nyroca* (Guldenstadt, 1770)	R, NT		•	•
75	Baer's Pochard	*Aythya baeri* (Radde, 1863)	M, CR	•		
76	Tufted Pochard	*Aythya fuligula* (Linnaeus, 1758)	RM, LC	•	•	
	Falconiformes ACCIPITRIDAE					
77	Black Baza	*Aviceda leuphotes* (Dumont, 1820)	RM, LC		•	
78	Oriental Honey-Buzzard	*Pernis ptilorhynchus* (Temminck, 1821)	RM, LC	•	•	
79	Black-Shouldered Kite	*Elanus caeruleus* (Desfontaines, 1789)	RM, LC	•	•	•
80	Black Kite	*Milvus migrans* (Boddaert, 1783)	R, LC	•	•	•
81	Brahminy Kite	*Haliastur indus* (Boddaert, 1783)	R, LC	•	•	
82	White-bellied Sea Eagle	*Haliaeetus leucogaster* (Gmelin, 1788)	R, LC	•		•
83	Pallas's Fish-eagle	*Haliaeetus leucoryphus* (Pallas, 1771)	M, VU	•		
84	Greater Grey-headed Fish-Eagle	*Ichthyophaga ichthyaetus* (Horsfield, 1821)	R, NT		•	
85	Egyptian Vulture	*Neophron percnopterus* (Linnaeus, 1758)	R, EN	•		
86	Indian White-backed Vulture	*Gyps bengalensis* (Gmelin, 1788)	R, CR	•	•	
87	Short-toed Snake-Eagle	*Circaetus gallicus* (Gmelin, 1788)	R, LC	•		•
88	Crested Serpent-Eagle	*Spilornis cheela* (Latham, 1790)	R, LC	•	•	
89	Western Marsh Harrier	*Circus aeruginosus* (Linnaeus, 1758)	M, LC	•	•	•
90	Pallid Harrier	*Circus macrourus* (S.G. Gmelin, 1770)	M, NT	•	•	•



Table 1 contd.

Sl. No.	Common Name	Species name	Status	East Coast	West Coast	Lakshadweep
91	Pied Harrier	*Circus melanoleucos* (Pennant, 1769)	M, LC	•	•	
92	Montagu's Harrier	*Circus phygargus* (Linnaeus, 1758)	M, LC	•		•
93	Crested Goshawk	*Accipiter trivirgatus* (Temminck, 1824)	R, LC		•	
94	Shikra	*Accipiter badius* (Gmelin, 1788)	R, LC	•	•	
95	Katchal Shikra	*Accipiter badius obsoletus* (Richmond, 1903)	R, LC			•
96	Besra Sparrowhawk	*Accipiter virgatus* (Temminck, 1822)	RM, LC	•	•	
97	Eurasian Sparrowhawk	*Accipiter nisus* (Linnaeus, 1758)	M, LC	•	•	
98	White-eyed Bazzard	*Butastur teesa* (Franklin, 1831)	R, LC		•	•
99	Long-legged Bazzard	*Buteo rufinus* (Cretzschmar, 1829)	M, LC		•	
100	Black Eagle	*Ictinaetus malayensis* (Temminck, 1822)	R, LC	•	•	
101	Lesser Spotted Eagle	*Aquila pomarina* Brehm, 1831	RM, NR	•		
102	Greater Spotted Eagle	*Aquila clanga* Pallas, 1811	M, VU	•	•	
103	Tawny Eagle	*Aquila rapax* (Temminck, 1828)	R, LC	•		
104	Steppe Eagle	*Aquila niplalensis* Hodgson, 1833	M, LC		•	
105	Eastern Imperial Eagle	*Aquila heliaca* Savigny, 1809	M, VU		•	
106	Bonelli's Eagle	*Hierraaetus fasciatus* (Vieillot, 1822)	M, VU			•
107	Booted Eagle	*Hieraaetus pennatus* (Gmelin, 1788)	R, LC	•	•	
108	Rufous-bellied Eagle	*Hieraaetus kienerii* (E. Geoffroy, 1835)	M, LC		•	
109	Changeable Hawk Eagle	*Spizaetus cirrhatus* (Gmelin, 1788)	R, LC	•	•	
	PANDIONIDAE					
110	Osprey	*Pandion haliaetus* (Linnaeus, 1758)	RM, LC	•	•	•
	FALCONIDAE					
111	Common Kestrel	*Falco tinnunculus* Linnaeus, 1758	RM, LC	•	•	•
112	Red-headed falcon	*Falco chicquera* Daudin, 1800	R, LC	•		
113	Eurasian Hobby	*Falco subbuteo* Linnaeus, 1758	M, LC		•	
114	Laggar Falcon	*Falco juggar* J.E. Gray, 1834	R, NT		•	
115	Amur Falcon	*Falco amurensis* Radde, 1863	M, LC			•
116	Peregrine Falcon	*Falco perigrinus* Tunstall, 1771	M, LC	•	•	•
	Gruiformes GRUIDAE					
117	Common crane	*Grus grus* (Linnaeus, 1758)	M, LC		•	
	TURNICIDAE					
118	Small Buttonquail	*Turnix sylvatica* (Des fontalis, 1789)	M, LC			•
	RALLIDAE					
119	Slaty-legged Crake	*Rallina eurizonoides* (Lafresnaye, 1845)	RM, LC	•	•	
120	Blue-breasted Rail	*Gallirallus striatus* Linnaeus, 1766	R, LC	•	•	
121	Water Rail	*Rallus aquaticus* Linnaeus, 1758	R, LC		•	
122	White-breasted Waterhen	*Amaurornis phoenicurus* (Pennant, 1769)	R, LC	•	•	•
123	Baillon's Crake	*Porzana pusilla* (Pallas, 1776)	RM, LC		•	•



Table 1 contd.

Sl. No.	Common Name	Species name	Status	East Coast	West Coast	Lakshadweep
124	Ruddy-breasted Crake	*Porzana fusca* (Linnaeus, 1766)	R, LC	•	•	
125	Watercock	*Gallicrex cinerea* (Gmelin, 1789)	RM, LC	•	•	•
126	Purple Moorhen	*Porphyrio porphyrio* (Linnaeus, 1758)	R, LC	•	•	•
127	Common Moorhen	*Gallinula chloropus* (Linnaeus, 1758)	RM, LC	•	•	•
128	Common Coot	*Fulica atra* Linnaeus, 1758	V, LC	•	•	•
	Charadriiformes JACANIDAE					
129	Pheasant tailed Jacana	*Hydrophasianus chirurgus* (Scopoli, 1786)	M, LC	•	•	
130	Bronze-winged Jacana	*Metopidius indicus* (Latham, 1790)	R, LC	•	•	
	ROSTRATULIDAE					
131	Greater Painted Snipe	*Rostratula benghalensis* (Linnaeus, 1758)	R, NR	•	•	
	HAEMATOPODIDAE					
132	Eurasian Oystercatcher	*Haematopus ostralegus* Linnaeus, 1758	M, LC	•	•	
	CHARADRIIDAE					
133	Pacific Golden-Plover	*Pluvialis fulva* (Gmelin, 1789)	M, LC	•	•	•
134	Grey Plover	*Pluvialis squatarola* (Linnaeus, 1758)	M, LC	•	•	•
135	Common Ringed Plover	*Charadrius hiaticula* Linnaeus, 1758	M, LC	•	•	•
136	Long-billed Plover	*Charadrius placidus* J.E. Gray & G.R. Gray, 1863	M, LC	•		
137	Little ringed plover	*Charadrius dubius* Scopoli, 1786	RM, LC	•	•	•
138	Kentish Plover	*Charadrius alexandrinus* Linnaeus, 1758	RM, LC	•	•	•
139	Lesser Sand Plover	*Charadrius mongolus* Pallas, 1776	RM, LC	•	•	•
140	Greater Sand Plover	*Charadrius leschenaultii* Lesson, 1826	M, LC	•	•	•
141	Caspian Plover	*Charadrius asiatucus* Pallas, 1773	V, LC			•
142	Black-fronted Dotterel	*Elseyornis melanops* (Vieillot, 1818)	V, LC	•		
143	Yellow-wattled Lapwing	*Vanellus malabaricus* (Boddaert, 1783)	R, LC	•	•	
144	Grey-headed Lapwing	*Vanellus cinereus* (Blyth, 1842)	M, LC	•		
145	Red-wattled Lapwing	*Vanellus indicus* (Boddaert, 1783)	R, LC	•	•	
146	White-tailed Lapwing	*Vanellus leucurus* (Lichtenstein, 1823)	M, LC	•	•	
	SCOLOPACIDAE					
147	Eurasian Woodcock	*Scolopax rusticola* Linnaeus, 1758	R, LC		•	
148	Wood Snipe	*Gallinago nemoricola* Hodgson, 1836	R, VU		•	
149	Pintail Snipe	*Gallinago stenura* (Bonaparte, 1831)	M, LC	•	•	
150	Swinhoe's Snipe	*Gallinago megala* Swinhoe, 1861	M, LC	•		
151	Common Snipe	*Gallinago gallinago* (Linnaeus, 1758)	RM, LC	•	•	
152	Jack Snipe	*Lymnocryptes minimus* (Brunnich, 1764)	M, LC	•	•	
153	Black-tailed Godwit	*Limosa limosa* (Linnaeus, 1758)	M, NT	•	•	•
154	Bar-tailed Godwit	*Limosa lapponica* (Linnaeus, 1758)	M, LC	•	•	•
155	Whimbrel	*Numenius phaeopus* (Linnaeus, 1758)	M, LC	•	•	•
156	Eurasian Curlew	*Numenius arquata* (Linnaeus, 1758)	M, NT	•	•	•
157	Spotted Redshank	*Tringa erythropus* (Pallas, 1764)	M, LC	•	•	
158	Common Redshank	*Tringa totanus* (Linnaeus, 1768)	RM, LC	•	•	•



Table 1 contd.

Sl. No.	Common Name	Species name	Status	East Coast	West Coast	Lakshadweep
159	Marsh Sandpiper	*Tringa stagnatilis* (Bechstein, 1803)	M, LC	•	•	
160	Common Greenshank	*Tringa nebularia* (Gunner, 1767)	M, LC	•	•	•
161	Spotted Greenshank	*Tringa guttifer* (Nordmann, 1835)	M, EN	•		
162	Green Sandpiper	*Tringa ochropus* Linnaeus, 1758	M, LC	•	•	•
163	Wood Sandpiper	*Tringa glareola* Linnaeus, 1758	M, LC	•	•	•
164	Terek Sandpiper	*Xenus cinereus* (Guldenstadt, 1775)	M, LC	•	•	•
165	Common Sandpiper	*Actitis hypoleucos* Linnaeus, 1758	M, LC	•	•	•
166	Ruddy Turnstone	*Arenaria interpres* (Linnaeus, 1758)	M, LC	•	•	•
167	Asian Dowitcher	*Limnodromus semipalmatus* (Blyth, 1848)	M, NT	•		
168	Great Knot	*Calidris tenuirostris* (Horsfield, 1821)	M, VU	•	•	•
169	Red Knot	*Calidris canutus* (Linnaeus, 1758)	M, LC	•		
170	Sanderling	*Calidris alba* (Pallas, 1764)	M, LC	•	•	•
171	Spoonbill Sandpiper	*Calidris pygmeus* (Linnaeus, 1758)	M, CR		•	
172	Little Stint	*Calidris minuta* (Leisler, 1812)	M, LC	•	•	
173	Rufous-necked Stint	*Calidris ruficollis* (Pallas, 1776)	M, LC	•		
174	Temminck's Stint	*Calidris. temminckii* (Leisler, 1812)	M, LC	•	•	
175	Long-toed Stint	*Calidris subminuta* (Middendorff, 1853)	M, LC	•	•	
176	Dunlin	*Calidris alpina* (Linnaeus, 1758)	M, LC	•	•	
177	Curlew Sandpiper	*Calidris ferruginea* (Pontoppidan, 1763)	M, LC	•	•	
178	Broad-billed Sandpiper	*Limicola falcinellus* (Pontoppidan, 1763)	M, LC	•	•	
179	Ruff	*Philomachus pugnax* (Linnaeus, 1758)	M, LC	•	•	
	RECURVIROSTRIDAE					
180	Black winged Stilt	*Himantopus himantopus* (Linnaeus, 1758)	RM, LC	•	•	•
181	Pied Avocet	*Recurvirostra avosetta* Linnaeus, 1758	M, LC	•	•	•
	PHALAROPIDAE					
182	Red-necked Phalarope	*Phalaropus lobatus* (Linnaeus, 1758)	M, LC	•		
183	Red Phalarope	*Phalaropus fulicaria* (Linnaeus, 1758)	M, LC		•	
	DROMADIDAE					
184	Crab-Plover	*Dromas ardeola* Paykull, 1805	M, LC	•		•
	BURHINIDAE					
185	Stone-Curlew	*Burhinus oedicnemus* (Linnaeus, 1758)	M, LC	•	•	•
186	Great Stone – Plover	*Esacus recurvirostris* (Cuvier, 1829)	R, LC	•	•	
187	Beach Stone-Plover	*Esacus magnirostris* (Vieillot, 1818)	R, LC	•		
	GLAREOLIDAE					
188	Indian Courser	*Cursorius coromandelicus* (Gmelin, 1789)	RM, LC		•	
189	Oriental Pranticole	*Glareola maldivarum* J.R. Forster, 1795	RM, LC	•	•	
190	Small Pratincole	*Glareola lactea* Temminck, 1820	RM, LC	•	•	
	Stercoraiidae					
191	Brown Skua	*Catharacta antarctica* (Lesson, 1831)	M, NR		•	



Table 1 contd.

Sl. No.	Common Name	Species name	Status	East Coast	West Coast	Lakshadweep
192	South Polar Skua	*Cantharacta maccormicki* (Saunders, 1893)	M, NR		•	
193	Pomarine jaeger	*Stercorarius pomarinus* (temminck, 1820)	M, NR		•	
194	Parasitic Jaeger	*Stercorarius parasiticus* (Linnaeus, 1758)	M, NR		•	
	LARIDAE					
195	Heuglin's Gull	*Larus heuglini* Bree, 1876	M, NR	•	•	
196	Yellow-legged Gull	*Larus cachinnans* Pallas, 1811	M, NR		•	
197	Lesser Black-backed Gull	*Larus fuscus* Linnaeus, 1758	M, LC		•	
198	Palla's Gull	*Larus ichthyaetus* Pallas, 1773	R, LC	•	•	
199	Brown-headed Gull	*Larus brunnicephalus* Jerdon, 1840	M, LC	•	•	•
200	Black-headed Gull	*Larus ridibundus* Linnaeus, 1766	M, LC	•	•	•
201	Slender-billed Gull	*Larus genei* Breme, 1839	R, LC		•	
202	Gull-billed Tern	*Gelochelidon nilotica* (Gmelin, 1789)	RM, LC	•	•	•
203	Black-naped Tern	*Sterna sumatrana* Raffles, 1822	RM, LC			•
204	Caspian Tern	*Sterna caspia* Pallas, 1770	M, LC	•	•	
205	River Tern	*Sterna aurantia* J.E. Gray, 1831	R, NT	•	•	
206	Lesser Crested Tern	*Sterna bengalensis* Lesson, 1831	R, LC	•	•	•
207	Large Crested Tern	*Sterna bergii* Lichtenstein, 1823	R, LC	•	•	•
208	Common Tern	*Sterna hirundo* Linnaeus, 1758	M, LC	•	•	
209	Little Tern	*Sterna albifrons* Pallas, 1764	M, LC	•	•	•
210	White-cheeked Tern	*Sterna repressa* Hartert, 1916	M, LC			•
211	Saunders's Tern	*Sterna saundersi* Hume, 1877	R, LC		•	
212	Roseate Tern	*Sterna duogalli* Montagu, 1813	R, LC	•		
213	Black-naped Tern	*Stern sumatrana* Raffles, 1822	R, LC			•
214	Black-bellied Tern	*Sterna acuticauda* J.E. Gray, 1831	R, EN	•	•	
215	Bridled Tern	*Sterna anaethetus* Scopoli, 1786	R, LC	•		•
216	Sooty Tern	*Sterna. fuscata* Linnaeus, 1766	R, LC	•	•	•
217	Sandwich Tern	*Sterna sandvicensis* Latham, 1787	M, LC	•	•	
218	Whiskered Tern	*Chlidonias hybridus* (Pallas, 1811)	R, LC	•	•	
219	White-winged Black Tern	*Chlidonias leucopterus* (Temminck, 1815)	M, LC	•	•	
220	Black Tern	*Chlidonias niger* (Linnaeus, 1758)	M, LC	•		
221	Black Noddy	*Anous minutus* Boie, 1844	M, LC			•
222	Brown Noddy	*Anous stolidus* (Linnaeus, 1758)	R, LC	•		•
223	Lesser Noddy	*Anous tenuurostris* (Temminck, 1823)	S, LC			•
	RYNCHOPIDAE					
224	Indian Skimmer	*Rynchops albicollis* Swainson, 1838	R, VU	•		
				165	**166**	**98**

R - Resident; RM - Resident Migrant; M - Transcontinental Migrant; S - Stragler; V - Vagrent

*LC-Least Concern; NT-Near Threatened; VU-Vulnerable; CR-Critically Endangered; EN-Endangered; NR-Not Recognised

* - BirdLife International (2012)



Table 2: Orderwise numerical status of coastal bird species

Sl. No.	Order	World[1]	Indian sub-continent[2]	East Coast	West Coast	Lakshadweep
1.	Podicipediformes	22	05	1	2	0
2.	Procellariiformes	32	21	0	0	7
3.	Pelecaniformes	45	17	6	9	8
4.	Ciconiiformes	88	34	26	23	19
5.	Phoenifopteriformes	06	02	2	2	1
6.	Anseriformes	145	44	18	16	3
7.	Falconiformes	285	71	28	29	14
8.	Gruiformes	186	33	8	11	7
9.	Charadriiformes	199	121	76	74	39
	Total	**1008**	**348**	**165**	**166**	**98**

1 - Harrison (1978); 2 - Ali and Ripley (1983); Ali, 1969

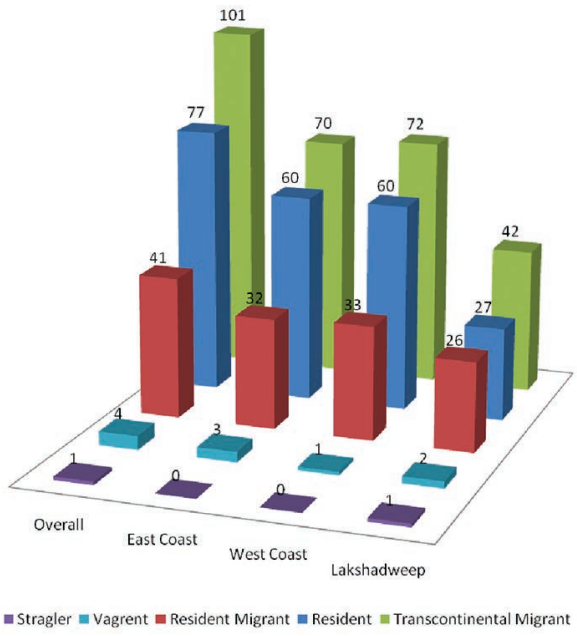


Fig. 1. Migratory status of birds of Coasts of India

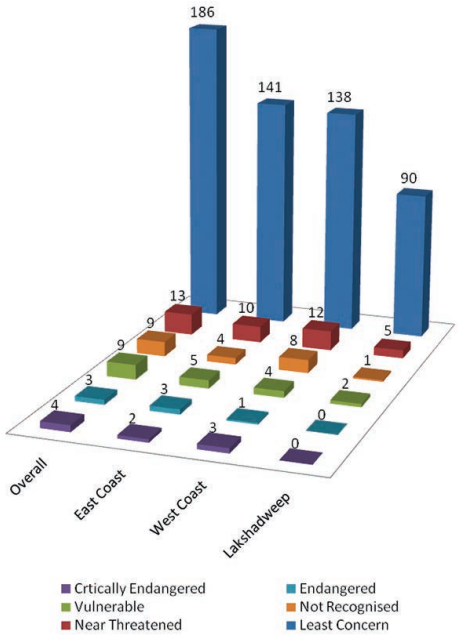


Fig. 2: Conservation status of bird of Coasts of India

In the present study, majority of the birds recorded in the coastal biogeographic zone are migrants (101 transcontinental migrants and 41 resident-migrant) (Fig. 1) showing high influx during the migration season. Large population of Lesser Crested and Large Crested Terns, migrating from Persian Gulf, is attracted by the intertidal zones Gulf of Kachchh of Saurashtra coast, and Gulf of Mannar. Northern Pintail, Garganey, Northern Shoveller, Eurasian Wigeon, being Arctic breeders migrate even to the southern most coastal zone of India. Migrants travel annually along the Centrtal Asian Flyway. Coastal birds, as primary and tertiary consumers cum predators, maintain the ecological balance in the coastal ecosystem. Besides, birds recycle the nutrients to the ecosystem through guano deposition to enhance the local fisheries. There are some important sites in the Coastal Biogeography Zone: The Point Calimere, The Pulicate, Gulf of Mannar and Chilka. The Point Calimere Wildlife Sanctuary (10°18' N; 79° 51' E) covering an area of about 349 km² has been well explored through bird ringing by BNHS, Mumbai, India. Birds ringed in countries like Russia, Kazakhstan, Uzbekistan, Poland, Saudi Arabia, Iran and Australia were recovered at Point Calimere in the same and subsequent seasons by BNHS. The Pulicat wetland situated between 13° 25' to 13° 55' N and 80° 03' to 80° 19'E with an area of about 450 sq. km makes it the second largest brackish water lagoon in India next to Chilika Lake. Over 200,000 waterbirds were recorded



during 1988 and 1989 at Pulicat. Out of them, over 30,000 were Greater Flamingo (Rao and Mohapatra 1993). Gulf of Mannar supported overall 50,000 coastal birds (waders, terns and other wading birds) including 13,000 flamingos during 1980s (Balachandran, 1990 and 1995) and it ranks third as an important wintering ground for Greater Flamingos *Phoenocopterus ruber* along the East Coast. Chilika Lake situated between 19° 28′ N and 19° 54′ N and between 85° 05′E and 85° 38′E attracts over 300, 000 waterbirds every year.

Of the recorded species, 29 were listed under IUCN threated categories (four critically endangered, three endangered, nine vulnerable and 13 near threatened-Figure 2). Species namely Spotted Greenshank *Tringa guttifer*, Spoonbill Sandpiper *Calidris pygmeus*, Dalmatian Pelican *Pelecanus crispus*, Spotbilled Pelican *Pelecanus philippensis*, Pallas's Fish-eagle *Haliaeetus albicilla*, Wood Snipe *Gallinago nemoricola* and Indian Skimmer *Rynchops albicollis,* Lesser Flamingo *Phoenicopterus minor*, Asian Dowitcher *Limnodromus semipalmatus*, Beach Stone-Plover *Esacus magnirostris* and Blackbellied Tern *Sterna acuticauda* are some of the important species, which are globally declining in numbers in recent years.

The Marine Protected Area Network in India has been used as a tool to protect the coastal habitats and their associated fauna. There are around 18 Marine Protected Areas, covering an area of about 6,158 sq.km, under the entire Protected Area Network of India (Sivakumar *et al.*, 2012; Sivakumar, 2012). Besides, India has also two (Sundarbans Tiger Reserve and Gulf of Mannar Biosphere Reserve) of 12 protected areas as trans-boundary protected areas under the framework of the IUCN Transboundary Protected Area Programme and one (Sundarbans National Park) of five UNESCO-World Heritage natural sites, in the Coastal Biogeographic Zone. (Sivakumar *et al.*, 2012). However, the extension of salt based industries, the diminishing rainfall and disturbances caused by fishermen have altered the coastal habitats in recent years. The increased ground water extraction and lack of ground water recharge lead to ingression of seawater into larger areas of the Coastal Biogeographi Zone. This in turn makes many areas not habitable for the coastal birds. Hence, a proper understanding of the ecology of migrant birds that exploit the Coastal Biogeographi Zone is an immense need to preserve both the birds and habitat.

ACKNOWLEDGEMENTS

The authors are grateful to the Director, Zoological Survey of India, Kolkata for his valuable support, encouragement and provision of necessary facilities.

REFERENCES

Acharya, S. and Kar, S.K., 1996. Checklist of Waders (Charadriiformes) in Chilika Lake, Orissa. Newsl. *Birdwatchers*, **36**(5): 89-90.

Ainley, D.G., 1978. Activity patterns and social behavior of nonbreeding Adelie Penguins. *Condor*, **80**: 138-146.

Ainley, D.G., 1980. Birds as marine organism: a review. *CalCOFI Rep*., **XXI**: 48-53.

Ainley, D.G. and Sanger, G.A., 1979**.** Trophic relationships of seabirds in the northeastern Pacific Ocean and Bering Sea. In: Bartonek, J.C. and Nettleship, D.N. (Eds.), *Conservation of marine birds in northern North America.* U.S. *Dept. Inter., Wildl. Res. Rept.* 11.

Ali, S. and Ripley, S.D., 1983. *Hand Book of the Birds of India and Pakistan*. Oxford University Press, Oxford, p. 737.

Anon., 1992. *Birds of Kole wetlands: A survey report – I*. Nature Education Society Thrissur (NEST), in collaboration with Kerala Forest Research Institute (KFRI) and Kerala Forest Department.p. 16.

Anon., 1993. *Birds of Kole wetlands: A Survey Report – II*. Nature Education Society Thrissur (NEST), in collaboration with Kerala Forest Research Institute (KFRI) and Kerala Forest Department. p. 18.

Balachandran, S., 1990: *Studies on the coastal birds of Mandapam and the neighbouring islands (Peninsular India)*. Ph.D. Thesis, Annamalai University, Annamalai Nagar, India. p. 229.

Balachandran, S., 1995: Shorebirds of the Gulf of Mannar Marine National Park, Tamil Nadu. J. *Bombay Nat. Hist. Soc*., **92**(3): 303-313.

Balachandran, S. 1998: Status of Spoonbilled Sandpiper Eurynorhynchos pygmaeus and Asian Dowitcher Limnodromus semipalmatus and threats to the waders in the Indian east coast. OBC Bull. **27**: 12-14.

Balachandran, S., 2006. The decline in wader population along the east coast of India with special reference to Point Calimere, South-east India. pp. 296-301. In: Waterbirds around the, world. (Eds). Boere, G.C., Galbraith, C.A. and Stroud, D.A. The Stationery Office, Edinburgh, UK.



Balachandran, S., 2012. Avian diversity in coastal wetlands of India and their conservation needs. pp. 155-163. In: *Marine Biodiversity, International Day for Biological Diversity, Uttar Pradesh Biodiversity Board*, UP.

Biju Kumar, A., 2006. A checklist of avifauna of the Bharathapuzha River Basin. Kerala. *Zoos' Print J.*, **21**(8): 2350-2355.

BirdLife International., 2012. The BirdLife checklist of the birds of the world, with conservation status and taxonomic sources. Version 5. Downloaded from http://www.birdlife.info/im/species/ checklist.zip.

Gopi, G.V. and Pandav, B., 2007. Avifauna of Bhitarkanika Mangroves. India. *Zoos' Print J.,* **229**(10): 2839-2847.

Grimmett, R., Inskipp, C. and Inskipp, T., 1998. *Birds of Indian Subcontinent*. Oxford, Oxford University Press, p. 888.

Harrison, C.J.O., 1978. *Bird Families of the World*. Elsevier Phaidon, Oxford, p. 264.

Jayson, E.A. and Easa, P.S., 2000. *Documentation of vertebrate fauna in Mangalavanam mangrove area.* KFRI Research Report No. 183. Kerala Forest Research Institute, Peechi. p. 42.

Jayson, E.A. and Sivaperuman, C., 2003. *Avifauna of Kol wetlands of Thrissur, a newly declared Ramsar Site in Kerala.* Regional Seminar on Ramsar sites of Kerala, 21st Feb. 2003, Kozhikode, Kerala.

Jayson, E.A. and Sivaperuman, C., 2004. Avifauna of Kole wetlands of Thrissur, a newly declared Ramsar Site in Kerala. pp. 27-47. In: *Proceeding of the National Seminar on Wetland Avian Ecology*, 15th Jan. 2004, St. Aloysius College, Elthuruth, Thrissur.

Jayson, E.A. and Sivaperuman, C., 2005. Avifauna of Thrissur district. Kerala. *Zoos' Print J*., **20**(2): 1774-1783.

Jisha Kurian, K., 2014. *Spatio-temporal variation of waterbirds in Kachchh, Gujarat, Western India*. Ph.D., Thesis. University of Madras, Chennai (Unpublished) p. 327.

Kannan, V. and Pandiyan, J., 2012. Shorebirds (Charadriidae) of Pulicat Lake. India with special reference to conservation. *World J. Zool.,* **7**(3): 178-191.

Kumar.A, Sali. J.P. and Tak, P.C., 2003. Checklist of Indian Waterbirds. *BUCERES. Envis Newsletter: avian Ecology of* & *Indian Wetlands,* **8**(1): 1-30.

Kurup, D.N., 1991. *Ecology of the birds of Malabar Coast and Lakshadweep*. Ph.D. Dissertation, University of Calicut, Calicut.

Kurup, D.N., 1996. *Ecology of the birds of Barathapuzha estuary and survey of the coastal wetlands of Kerala*. Final Report submitted to Kerala Forest Department, Trivandrum. p. 59.

Manakadan, R. and Pittie, A., 2001. Standardised Common and Scientific Names of the Birds of the Indian Subcontinent. *Buceros*, **6**(1): 1-37.

Mohapatra, K.K., 1998. *Food and feeding habits of important aquatic birds of Chilika Lake Orissa*. Final report. Bombay Natural History Society, Mumbai. Pp. 1-150.

Nagarajan, R. and Thiyagesan, K., 1996. Waterbirds and substrate quality of the Pichavaram wetlands. Southern India. *Ibis*, **138**: 710-721.

Oswin, D.S., 1999. Avifaunal diversity of Muthpet Mangrove Forest. *Zoos' Print J.*, **14**(6): 47-53.

Pawar, P.R., 2011. Species diversity of birds in mangroves of Uran (Raigad), Navi Mumbai, Maharashtra. West coast of India. *J. Experim. Sci.*, **2**(10): 73-77.

Ramamurthy, V. and Rajakumar, R., 2014. A study of avifaunal diversity and influences of water quality in the Udhayamarthandauram Bird Sanctuary, Thiruvarur District. Tamil Nadu. *Int. J. Innovative Res. Sci. Engg. Tech*. **3**(1): 8851-8858.

Rajpar, M.N. and Zakaria, M., 2009. Assessment of waterbirds at Paya Indah Wetland Reserve, Peninsular Malaysia. In: *Proceedings of the UTM 8th Annual Symposium on Sustainability Science and Management*, Kuala Terengganu, Peninsular Malaysia, Malaysia, March 2009. Pp. 606-612.

Rao, P. and Mohapatra, K.K., 1993. The wetland avifauna of Pulicat Bird Sanctuary, South India. Pp. 11-14. In: Verghese, A., Sridhar, S. and Chakravarthy, A.K (Eds.), *Bird Conservation - Strategies for the nineties and beyond*. Ornithological Society of India, Bangalore.

Rodgers, W.A., Panwar, H.S. and Mathur, V.B., 2000. Wildlife protected area network in India: *A review. Wildlife Institute of India, Dehra Dun, India*. p. 44.



Sampath, K., 1989. *Studies on the ecology of Shorebirds (Aves: Charadriiformes) of the Great Vedaranyam Swamp and the Pichavaram Mangroves of India*. Ph.D. Dissertation, Annamalai University, Tamil Nadu. p. 202.

Sampath, K. and Krishnamurthy, K., 1989. Shore birds of the salt ponds at Great Vedaranyam Salt Swamp. *Stilt*, **15**: 20-23.

Sanger, G.A., 1972. Preliminary standing stock and biomass estimates of seabirds in the subarctic Pacific region. pp. 589-611.

Takenouti *et al.* (Eds.), Biological oceanography of the northern North Pacific Ocean, Idemitsu Shoten, Tokyo.

Schneider, D., 1978. Equalisation of prey numbers by migratory shorebirds. *Nature*, **271**: 353-354

Scott, D.A., 1989. A directory of Asian Wetlands. Gland, Switzerland, IUCN

Sivakumar, K., 2012. Marine biodiversity conservation in India. *Go4BioDiv Newsletter*, **2**(2): 10-12 27.

Sivakumar, K., Mathur, V.B. and Choudhury, B.C., 2012. Marine Protected Areas Network in India: Progress in Achieving Aichi Targets. *Abstracts of 16th Meeting of Subsidiary Body on Scientific, Technical and Technological Advice*. 30 April - 5 May 2012 - Montreal, Canada. 78-79.

Sivaperuman, C., 2011. Avian communities of Ritchie's Archipelago, Andaman and Nicobar Islands. pp. 238. In: *Proceeding of the International conference on Tropical Island Ecosystem: Issues related to livelihood, sustainable development and climate change*. Central Agricultural Research Institute, Port Blair.

Sivaperuman, C., 2013. Diversity and species-abundance distribution of birds in the Ritchie's archipelago. Andaman and Nicobar Islands. *Ann. Forestry,* **21**(1): 101-112.

Sivaperuman, C. and Jayson, E.A., 2000. Birds of Kole Wetlands, Thrissur. Kerala. *Zoos' Print J.* **15**(10): 344-349.

Sivaperuman, C. and Jayson, E.A., 2009. Population dynamics of wetland birds in the Kole wetlands of Kerala. India. *J. Sci. Trans. Environ. Tech*., **2**(3), 152-162.

Sivaperuman, C., Venkatraman, C. and Raghunathan, C., 2010. Avifauna of Andaman and Nicobar Islands: An Overview. pp. 399-412. In: Ramakrishna, Raghunathan, C. and Sivaperuman, C. (Eds)., *Recent Trends in Biodiversity of Andaman and Nicobar Islands*, Zoological Survey of India.

Venkataraman, K., 2008. Coastal and Marine wetlands in India. pp. 392–400. In: Sengupta, M. and Dalwani, R. (Eds.), *Proceedings of Taal 2007*. The 12th World Lake Conference, Ministry of Environment and Forests, Govenment of India, New Delhi.

Venkatraman, C., 2008. Diversity of Coastal birds in Gulf of Mannar Biosphere Reserve, Southern India. In: Reddy, M.V. (Ed.), *Wildlife Biodiversity Conservation in India*. Daya publishing house, New Delhi. pp 104-113.

Venkatraman, C. and Gokula, V., 2009. Coastal birds of Tamil Nadu. *Rec. zool. Surv. India. Occ. Paper,* **303**: 1-64.

Venkatraman, C. and Muthukrishnan, S., 1993. Density of waterbirds at Vedanthangal Bird Sanctuary, Tamil Nadu. pp. 55-60. In: Verghese, A., Sridhar, S. and Chakravarthy, A.K. (Eds.), *Bird Conservation: Strategies for the Nineties, Beyond*. Ornithological Society of India, Bangalore.

Verma, A., Chaturvedi, N., Balachandran, S. and Kehimkar, I., 2002. Avian diversity in and around Mangroves and Mahul Creeks Mumbai, India. *Proc. The National Seminar on Creeks, Estuaries and Mangroves – pollution and conservation*. pp. 266-275.



PLATE



Brown-headed Gull (*Larus brunnicephalus* Jerdon, 1840)



Black-tailed Godwit (*Limosa Limosa* Linnaeus, 1758)



Pin-tailed snipe (*Gallinago stenura* Bonaparte, 1831)



Wood sandpiper (*Tringa glareola* Linnaeus, 1758)



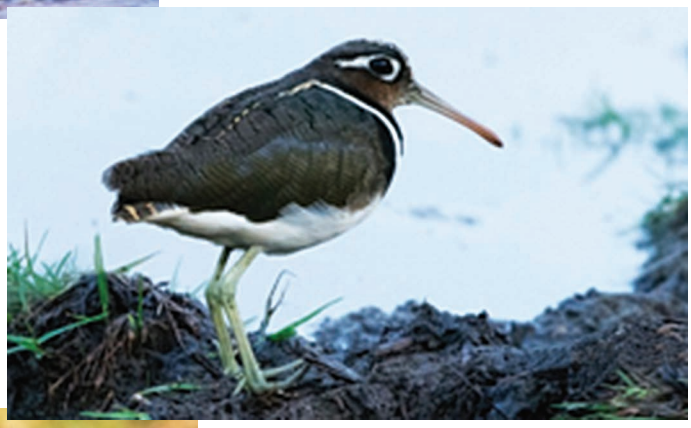
Northern shoveller (*Anas Poecilorhyncha* J.R. Forester, 1781)



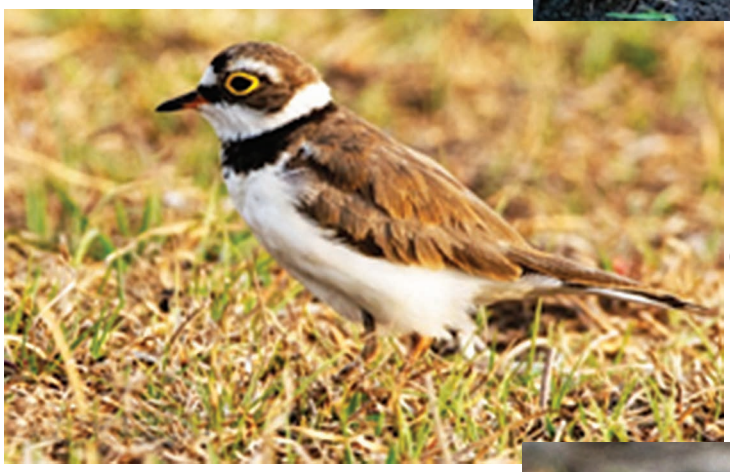
PLATE



Oystercatcher (*Haematopus ostralegus* Linnaeus, 1758)



Greater painted snipe
(*Rostratula benghalensis* Linnaeus, 1758)



Little-ringed Plover
(*Charadrius dubius* Scopoli, 1786)



Kentish Plover
(*Charadrius alexandrinus* Linnaeus, 1758)

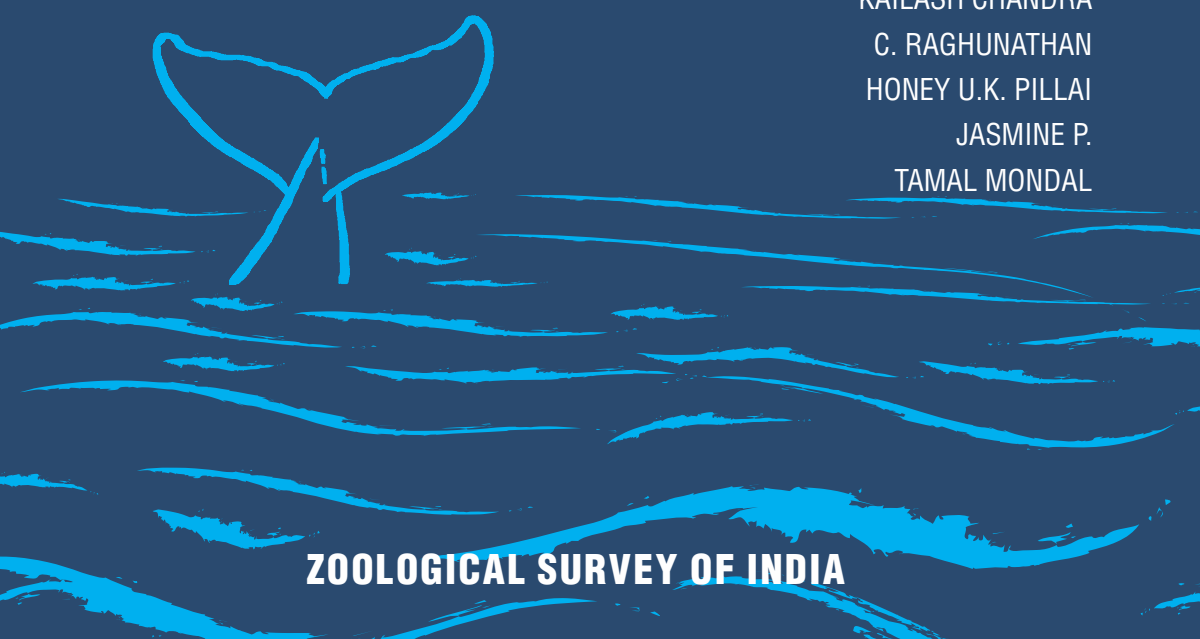
Ministry of Environment,
Forest and Climate Change

सत्यमेव जयते

ZOOLOGICAL SURVEY
OF INDIA
1916

Deep Sea
Faunal Diversity in India

KAILASH CHANDRA
C. RAGHUNATHAN
HONEY U.K. PILLAI
JASMINE P.
TAMAL MONDAL

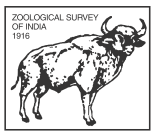


ZOOLOGICAL SURVEY OF INDIA



Ministry of Environment,
Forest and Climate Change





Deep Sea
Faunal Diversity in India

KAILASH CHANDRA | C. RAGHUNATHAN
HONEY U.K. PILLAI | JASMINE P. | TAMAL MONDAL

ZOOLOGICAL SURVEY OF INDIA
Ministry of Environment, Forest and Climate Change
Government of India

CITATION

Chandra, K., Raghunathan, C., Pillai, H.U.K., Jasmine P. and Mondal, T., 2021. *Deep Sea Faunal Diversity in India:* 1-634 (Published by the Director, Zool. Surv. India, Kolkata).

Published : February, 2021

ISBN 978-81-8171-569-2

© *Govt. of India,* 2021

Disclaimer

It is hereby claimed that any views or opinions presented in the articles published in this book are solely those of the authors. The editor or the Zoological Survey of India have not independently verified the information gathered or contained in this book and, accordingly expressed no opinions or makes any representation concerning its accuracy or complete reliability or sufficiency. The ZSI disclaim any and all liability for, or based on or relating to any such information and/or contained in, or errors in or in omissions from, their inputs or information in this book. The ZSI will not accept any liability in respect of such communication, and the authors responsible will be personally liable for any damages or other liability arising.

Price
India : ₹ 2696.00
Foreign : $ 110 ; £ 80

Published at the Publication Division by the Director, Zoological Survey of India, M-Block, New Alipore, Kolkata-700 053 and designed & printed by Graf-M Printers, Kolkata-700 025.

मंत्री
पर्यावरण, वन एवं जलवायु परिवर्तन,
सूचना एवं प्रसारण और
भारी उद्योग एवं लोक उद्यम
भारत सरकार

MINISTER
ENVIRONMENT, FOREST & CLIMATE CHANGE,
INFORMATION & BROADCASTING AND
HEAVY INDUSTRIES & PUBLIC ENTERPRISES
GOVERNMENT OF INDIA

सत्यमेव जयते

स्वच्छ भारत
एक कदम स्वच्छता की ओर

प्रकाश जावडेकर
Prakash Javadekar



MESSAGE

The ocean generates nearly half of the oxygen in the atmosphere, absorbs huge quantities of carbon dioxide, governs climate and weather, regulates temperature and harbours great abundance and diversity of life on Earth. Marine scientific research provides the basis for understanding of oceanic processes and ecosystems which are essential ingredients for their rational conservation and management.

Marine research in the open ocean and deep seabed for scientific and commercial purposes is set to develop in order to fill the large gaps in our knowledge of these extreme environments. Considering biological as well as geological significance of the Indian Ocean, Government of India is launching 'Deep Sea Mission' that envisages exploration of minerals, energy and marine diversity of the central Indian Ocean, coinciding with the proclamation of Decade of Ocean Science for Sustainable Development (2021-2030).

Understanding the importance of deep sea ecosystem in terms of its biodiversity and bioprospecting, I am happy to note that Zoological Survey of India has made an attempt to collate the information on deep sea fauna in Indian Ocean region based on its surveys over the period of 100 years and brought out the volume entitled, *'Deep Sea Faunal Diversity in India'* which is first of its kind publication in India on deep sea fauna.

I am confident that this book will serve as a baseline information on deep sea fauna and serve as a valuable source for conserving and managing the deep sea bio-resources in Indian Economic Zone for sustainable utilization. I congratulate the entire team of Zoological Survey of India for bringing out this important document.

Date: 22.02.2021

(Prakash Javadekar)

पर्यावरण भवन, जोर बाग रोड़, नई दिल्ली-110 003 फोन : 011-24695136, 24695132, फैक्स : 011-24695329
Paryavaran Bhawan, Jor Bagh Road, New Delhi-110 003, Tel.: 011-24695136, 24695132, Fax : 011-24695329
ई-मेल/E-mail : minister-efcc@gov.in

CONTRIBUTING AUTHORS

1. **Kailash Chandra**
   Zoological Survey of India, M-Block, New Alipore, Kolkata – 700 053, West Bengal

2. **Aishee Bhowal**
   Zoological Survey of India, M-Block, New Alipore, Kolkata – 700 053, West Bengal

3. **Alfisa Siddique**
   Zoological Survey of India, M-Block, New Alipore, Kolkata – 700 053, West Bengal

4. **Ameri Kottarathil Helna**
   Department of Aquatic Biology and Fisheries, University of Kerala, Karyavattom, Thiruvananthapuram-695 581, Kerala

5. **Amit Kumar Mukhopadhyay**
   Zoological Survey of India, M-Block, New Alipore, Kolkata – 700 053, West Bengal

6. **Appukuttannair Biju Kumar**
   Department of Aquatic Biology and Fisheries, University of Kerala, Karyavattom, Thiruvananthapuram-695 581, Kerala

7. **Arya MS**
   Zoology Research Centre, St. Stephens College, Pathanapuram, University of Kerala, Kollam – 689 695, Kerala

8. **Barbilina Pam**
   Zoological Survey of India, M-Block, New Alipore, Kolkata – 700 053, West Bengal

9. **Basudev Tripathy**
   Zoological Survey of India, M-Block, New Alipore, Kolkata – 700 053, West Bengal

10. **Biju A.**
    Zoology Research Centre, St. Stephens College, Pathanapuram, University of Kerala, Kollam – 689 695, Kerala

11. **Bineesh K.K.**
    Zoological Survey of India, Andaman and Nicobar Regional Centre, Port Blair – 744 102, Andaman and Nicobar Islands

12. **C. P. Rajool Shanis**
    Research Department of Aquaculture and Fishery Microbiology, MES Ponnani College, Kerala

13. **C. Raghunathan**
    Zoological Survey of India, M-Block, New Alipore, Kolkata – 700 053, West Bengal

14. **C. Surendar**
    Zoological Survey of India, Marine Biology Regional Centre, 130, Santhome High Road, Chennai-600 028, Tamil Nadu

15. C. Venkatraman
Zoological Survey of India, M-Block, New Alipore, Kolkata – 700 053, West Bengal

16. Ch. Satyanarayana
Zoological Survey of India, Marine Biology Regional Centre, 130, Santhome High Road, Chennai-600 028, Tamil Nadu

17. Daizy Bharti
Zoological Survey of India, M-Block, New Alipore, Kolkata – 700 053, West Bengal

18. Gisha Sivan
Department of Zoology, Sacred Heart College, Thevara-682 013, Kerala

19. Honey U. K. Pillai
Zoological Survey of India, M-Block, New Alipore, Kolkata – 700 053, West Bengal

20. J.S. Yogesh Kumar
Zoological Survey of India, Marine Aquarium and Regional Centre, Digha – 721 428, West Bengal

21. Jasmine Purushothaman
Zoological Survey of India, M-Block, New Alipore, Kolkata – 700 053, West Bengal

22. Jhimli Mondal
Centre for Marine Living Resources and Ecology, Kendriya Bhavan, Block – C, Kakkanad, Kochi-682 037, Kerala

23. Jini Jacob
Cochin University of Science and Technology, Cochin-682 016, Kerala

24. K. Valarmathi
Zoological Survey of India, FPS Building, Indian Museum complex, Kolkata-700 016, West Bengal

25. Kadeparambil Arjunan Jayaraj
Department of Ocean Studies and Marine Biology, Pondicherry University, Port Blair-744 103, Andaman and Nicobar Islands

26. Meera K.M.
Centre for Marine Living Resources and Ecology, Kochi, Kerala

27. Mohammed Naufal
Department of Ocean Studies and Marine Biology, Pondicherry University, Port Blair-744 103, Andaman and Nicobar Islands

28. N. Marimuthu
Zoological Survey of India, FPS Building, Indian Museum Complex, Kolkata-700 016, West Bengal

29. Nair KKC
CSIR National Institute of Oceanography, Regional Centre, Kochi, Kerala

30. Nosad Sahu
Department of Ocean Studies and Marine Biology, Pondicherry University Off Campus, Brookshabad, Port Blair – 744 112, Andaman and Nicobar Islands

31. Oishinee Chakraborty
Zoological Survey of India, Andaman and Nicobar Regional Centre, Port Blair – 744 102, Andaman and Nicobar Islands

32. P.M. Mohan
Department of Ocean Studies and Marine Biology, Pondicherry University Off Campus, Brookshabad, Port Blair – 744 112, Andaman and Nicobar Islands

33. Panakkool Thamban Aneesh
Department of Aquatic Biology and Fisheries, University of Kerala, Karyavattom, Thiruvananthapuram-695 581, Kerala

34. Preeti Pereira
Zoological Survey of India, Andaman and Nicobar Regional Centre, Port Blair – 744 102, Andaman and Nicobar Islands

35. R. Damodaran
Cochin University of Science and Technology, Cochin-682 016, Kerala

36. Raj Kiran Lakra
Department of Ocean Studies and Marine Biology, Pondicherry University Off Campus, Brookshabad, Port Blair – 744 112, Andaman and Nicobar Islands

37. S. Balakrishnan
Zoological Survey of India, Marine and Aquarium Regional Centre, Digha – 721 428, West Bengal

38. S.K. Sajan
Zoological Survey of India, M-Block, New Alipore, Kolkata – 700 053, West Bengal

39. S.S. Mishra
Zoological Survey of India, FPS Building, Indian Museum Complex, Kolkata-700 016, West Bengal

40. Santosh Kumar
Zoological Survey of India, M-Block, New Alipore, Kolkata – 700 053, West Bengal

41. Seepana Rajendra
Zoological Survey of India, Andaman and Nicobar Regional Centre, Port Blair – 744 102, Andaman and Nicobar Islands

42. Smruthu Mohan
ICAR- Central Marine Fisheries Research Institute, Mangaluru, Karnataka, India

43. Sonia Mondal
Zoological Survey of India, M-Block, New Alipore, Kolkata – 700 053, West Bengal

44. Subhadeep Ghosh
Zoological Survey of India, M-Block, New Alipore, Kolkata – 700 053, West Bengal

45. T. Ganesh
Department of Ocean Studies and Marine Biology, Pondicherry University Off Campus, Brookshabad, Port Blair – 744 112, Andaman and Nicobar Islands

46. Tamal Mondal
Zoological Survey of India, Andaman
and Nicobar Regional Centre,
Port Blair – 744 102, Andaman and
Nicobar Islands

47. V. Gokula
PG and Research Department of
Zoology, National College,
Tiruchirappalli – 620 001, Tamil Nadu

48. V.N. Sanjeevan
Kerala University of Fisheries and
Ocean Studies, Kochi, Kerala

CONTENTS

Chapter 1	**Deep-sea biodiversity of India- an overview** Kailash Chandra, C. Raghunathan, Tamal Mondal, Honey U. K. Pillai and Jasmine Purushothaman	1-22
Chapter 2	**Protozoa: Ciliata (Planktonic)** Smruthu Mohan, Daizy Bharti, Subhadeep Ghosh, Jasmine Puroshothaman and Santosh Kumar	23-39
Chapter 3	**Foraminifera (Planktonic)** Barbilina Pam and P.M. Mohan	41-51
Chapter 4	**Foraminifera (Benthic)** P.M. Mohan and Barbilina Pam	53-94
Chapter 5	**Radiolaria** Aishee Bhowal, Jasmine Purushothaman, C. Raghunathan and Kailash Chandra	95-109
Chapter 6	**Dinoflagellata** Aishee Bhowal, Jasmine Purushothaman, C. Raghunathan and Kailash Chandra	111-131
Chapter 7	**Porifera: Hexactinellida** Preeti Pereria and C. Raghunathan	133-139
Chapter 8	**Cnidaria: Scleractinia** Tamal Mondal and C. Raghunathan	141-150
Chapter 9	**Cnidaria: Octocorallia** J. S. Yogesh Kumar	151-166
Chapter 10	**Cnidaria: Hydrozoa** Oishinee Chakraborty, Alfisa Siddique, Jasmine Purushothaman, C. Raghunathan and Kailash Chandra	167-185

Chapter 11	**Cnidaria: Scyphozoa** Tamal Mondal and C. Raghunathan	187-193
Chapter 12	**Ctenophora** Alfisa Siddique, Jasmine Purushothaman, C. Raghunathan and Kailash Chandra	195-202
Chapter 13	**Nematoda** Jini Jacob and R. Damodaran	203-238
Chapter 14	**Sipuncula** Tamal Mondal and C. Raghunathan	239-245
Chapter 15	**Echiura** Tamal Mondal and C. Raghunathan	247-251
Chapter 16	**Annelida: Polychaeta** T. Ganesh, Nosad Sahu, Raj Kiran Lakra and S. Balakrishnan	253-272
Chapter 17	**Arthropoda: Pycnogonida** Tamal Mondal and C. Raghunathan	273-277
Chapter 18	**Arthropoda: Crustacea: Copepoda (Planktonic)** Honey U. K. Pillai and Biju A.	279-300
Chapter 19	**Arthropoda: Crustacea: Ostracoda** Alfisa Siddique, Jasmine Purushothaman, C. Raghunathan and Kailash Chandra	301-322
Chapter 20	**Arthropoda: Crustacea: Mysida** Biju A. and Honey U. K. Pillai	323-328
Chapter 21	**Arthropoda: Crustacea: Amphipoda: Hyperiidea** Nair K. K. C., Biju A. and Honey U. K. Pillai	329-338
Chapter 22	**Arthropoda: Crustacea: Isopoda (Parasitic Cymothoids)** Panakkool Thamban Aneesh, Ameri Kottarathil Helna and Appukuttannair Biju Kumar	339-351

Chapter 23	**Arthropoda: Crustacea: Euphausiacea** Gisha Sivan, Honey U. K. Pillai and Biju A.	347-356
Chapter 24	**Arthropoda: Crustacea: Decapoda: Luciferidae (Planktonic Decapod)** Biju A, Honey U. K. Pillai and Arya M. S.	357-360
Chapter 25	**Arthropoda: Crustacea: Decapoda (Shrimps)** C. P. Rajool Shanis and Bineesh K. K.	361-374
Chapter 26	**Arthropoda: Crustacea: Decapoda (Lobsters)** C. P. Rajool Shanis and Bineesh K. K.	375-382
Chapter 27	**Crabs** K. Valarmathi	383-402
Chapter 28	**Bryozoa** Mohammed Naufal, Kadeparambil Arjunan Jayaraj and C. Venkatraman	403-430
Chapter 29	**Brachiopoda** Tamal Mondal and C. Raghunathan	431-434
Chapter 30	**Chaetognatha** Alfisa Siddique, Jasmine Purushothaman, C. Raghunathan and Kailash Chandra	435-446
Chapter 31	**Mollusca: Cephalopoda** Basudev Tripathy, Amit Kumar Mukhopadhyay and S. K. Sajan	447-455
Chapter 32	**Mollusca: Pteropoda** Alfisa Siddique, Jasmine Purushothaman, C. Raghunathan and Kailash Chandra	457-469
Chapter 33	**Molluscs** S. Rajendra, Tamal Mondal and C. Raghunathan	471-482
Chapter 34	**Echinodermata** C. Surendar, N. Marimuthu and Ch. Satyanarayana	483-509

Chapter 35	**Chordata: Tunicata: Ascidiacea (Urochordates)** Jhimli Mondal and C. Raghunathan	517-523
Chapter 36	**Pisces** K. K. Bineesh, S. S. Mishra and K. Chandra	525-555
Chapter 37	**Pisces (Myctophids)** Meera K. M. and V. N. Sanjeevan	557-570
Chapter 38	**Reptilia: Elapidae: Hydrophiinae** Sonia Mondal and C. Raghunathan	571-584
Chapter 39	**Marine Turtles** Basudev Tripathy	585-610
Chapter 40	**Pelagic Avifauna** V. Gokula and C. Venkataraman	611-624
Chapter 41	**Marine Mammals** Tamal Mondal and C. Raghunathan	625-634

Chapter 40

PELAGIC AVIFAUNA



V. Gokula[*1] and C. Venkataraman[2]

Pelagic birds spend greater part of their life on open Ocean and return to land for a shorter period only to breed. As they are found only far out to sea, understanding their status and ecology is often challenging. Hence, unlike other group of birds, pelagic birds are poorly studied in India.India, with a long coastline of nearly 7500 km, shares its maritime boundary with seven countries. India harbours around 72 pelagic species of birds belonging to five orders and nine families. Of the 72 species, 15 breed in Indian Territories while the rest are mere migrants/vagrants to India. Birds belonging to phaethontiformes and suliformes are truly pelagic in habitat and often sighted in poor numbers. Habitatloss, climate change, and pollution are the immediate threats to pelagic birds.

Keywords: oceanic, pelagic, marine, avifauna

INTRODUCTION

Pelagic birds spend a significant portion of its life on open Ocean and return to land for a shorter period only to breed. They have salt glands to extract excess salt accumulated due to the intake of oceanic prey and marine water and thus without accumulating toxic levels of salt in their bloodstreams. These two unique characters differentiate the pelagic birds from the rest of the birds. However, as there are disagreements about what makes a bird species truly pelagic, even birds that do not share the above mentioned characters are also treated as pelagic birds. Pelagic birds belong to the orders namely Phaethontiformes (tropic birds), gaviiformes (loons/divers), procellariiformes (storm petrels, petrels, shearwaters), suliformes (frigatebirds, gannets and boobies), and charadriiformes (gulls, terns, skimmers, skuas). However, there are disagreements among scientists in the inclusion of all the species of birds belonging to above mentioned orders as pelagic birds. Birds belonging to other orders due to their strong association with coastal habitats are considered near-pelagic despite the fact that they are not seabirds in the formal sense (eg. Cormorants and pelicans).

[1]PG and Research Department of Zoology, National College, Tiruchirappalli – 620 001, Tamil Nadu, Kerala. [2]Zoological Survey of India, M- Block, New Alipore, Kolkata-700 053, West Bengal, India. *Corresponding author's Email: gokulae@yahoo.com

Besides, wings of true pelagic birds are best suited to fly effortlessly for long periods without rest for thousands of miles offshore. They do occasionally rest or float on the surface of the water for a brief period. Being oceanic in habit, they feed on marine organism such as fish, squid, and crustaceans by plunging/skimming. Besides, they are opportunistic/refined kleptoparasites. As they are found only far out to sea, understanding their status and ecology is often challenging. Pelagic touring is the only way to study the pelagic birds. As it is very expensive and time consuming, opportunistic birding by professional/non proessionl on a cruise vacation is often included to understand the status of pelagic birds. Hence, unlike other group of birds, pelagic birds are poorly studied in India.

India has around 7500 km coastline. It shares its coastal boundary with seven countries namely Indonesia, Pakistan, Thailand, Sri Lanka, Maldives, Bangladesh, and Myanmar. It has a 12 nautical-miles territorial sea and 200 nautical miles exclusive economic zone covering a territory of nearly 314,400 square kilometers. Successful delineation of maritime boundary is very much important for scientific explorations. India has maritime boundary demarcated with Pakistan in 1968, with Maldives in 1976, with Sri Lanka in 1976, with Indonesia in 1977, with Thailand in 1978, with Myanmar in 1986, and with Bangladesh in 2014. However, Sir Creek issue with Pakistan and fisherman issue of Sri Lanka are the two major maritime disputes in which India is involved at present. India's offshore islands are Andaman and Nicobar Islands, situated in the Bay of Bengal, and Lakshadweep, situated in the Arabian Sea. Andaman has 204 Islands while Nicobar has 19 Islands. Lakshadweep comprises 36 islands. Birds that exploit the above mentioned Indian marine territory are only dealt in the present study.

India has diverse habitat types (tidal flats, rocky shore, coastal dunes, mudflats, mangroves, wetlands, marshes, seaweed and seagrass bed, deltaic plains, lagoons, estuaries, and coral reefs) for pelagic birds to forage and breed. However, unlike forest birds and wetland birds, no systematic study on species level or community level on pelagic birds has been undertaken in India, leading to a paucity of data. Hence, the available records were based on wind-blown individuals sighted/collected from onshore and a few offshore expeditions (Hume, 1876; Abdulali, 1970; Madsen, 1990; Mohan, 1989; Lainer, 2003; Pande *et al*., 2007, Mathew and Ambedkar, 1964; Daniels, 1992). Praveen *et al*. (2011) initiated the firstexclusive pelagic bird survey by conducting three offshore expeditions from Kerala. Subsequently, Praveen (2014) conducted another survey off the west and east coast. Recently, Baidya *et al.* (2017) conducted a survey off the Goa.

PELAGIC BIRDS OF INDIA

In general, India harbours around 72 species of pelagic birds (Table 1) belonging to five orders (phaethontiformes, gaviiformes, procellariiformes, suliformes, and charadriiformes) and nine families (Phaethontidae, Gaviidae, Oceanitidae, Hydrobatidae, Procellariidae, Fregatidae, Sulidae, Laridae, and Stercorariidae).

Three species belonging to phaethontiformes namely Red-billed Tropicbird *Phaethon aethereus* Red-tailed Tropicbird *Phaethon rubricauda* and White-tailed Tropicbird

*Phaethon lepturus*are recorded in India. All the three are truly pelagic in habitat. Among the three species, the white-tailed tropicbird was recorded from Rameshwaram, Tamil Nadu by Balachandran (1992), from River Barrak by Hume (1877) and Rasmussen and Anderton (2005), at Kovalam, Kerala by (Sashikumar *et al.,* 2011) and from northern Kerala by Palot (2011). Redbilled tropic bird was recently sighted at Kozhikode by Palot (2003). Harrison (1983) reported that among the three species, only red-tailed tropic bird breeds in Nicobar Islands.

Two species belonging to gaviiformes namely Red-throated Loon *Gaviastellata* Arctic Loon *Gaviaarctica* are recorded in India (Ali and Ripley 1983). Both are treated as vagrant to India. However, Red-throated Diver, an holarctic species, breeding largely north of 50° N and far into the high arctic, and wintering mainly along the north coasts of the Atlantic and Pacific Oceans as well as in several major lakes and seas such as the Great Lakes and the Black, Caspian and Mediterranean Seas (del Hoyo *et al.,* 1992), was not reported from India. Available two records are from Nepal (Ticehurst 1927; Tebb *et al.*, 2004). Unusual weather phenomenon was reported possible reason for these records in Nepal. Two reports (Jones, 1922; Steijn and Vries, 2009) confirmed the presence of Black-throated Diver/Arctic Loon *Gavia arctica* (Linnaeus, 1758) in Indian boundary.

Three species belonging to the order Procellariiformes and the family Oceanitidae namely Wilson's Storm-petrel *Oceanites oceanicus,* White-faced Storm-petrel *Pelagodroma marina,* and Black-bellied Storm-petrel *Fregetta tropica* are recorded in India. Wilson's Storm-petrel breeds in the sub-Antarctic region in the Southern Ocean and is considered a non-breeding visitor off the western coast of India, Lakshadweep (Rasmussen and Anderton 2005) and Indo-Sri Lankan water (Phillips, 1955; Sashikumar *et al.,* 2011; Robertson, 1994). Harrison (1983) reported that White-faced Storm-petrel and Black-bellied Storm-petrel are rare vistors or vagrants to southwest coastal waters of India. Among the storm petrels, Wilson's storm-petrel is reported the commonest (Chandran *et al.,* 2011; Praveen *et al*., 2011; Karuthedathu *et al*., 2013)

One species belonging to the order procellariiformes and the family Hydrobatidae namely Swinhoe's Storm-petrel *Hydrobates monorhis* are recorded in India. Rasmussen and Anderton (2005) reported Swinhoe's Storm-petrels as unconfirmed non-breeding visitor to India, however, sashikumar *et al.* (2011) and Vivek *et al.* (2011) confirmed its range in Indian coast while Chandran *et al.* (2011) reported it as common.

Ten species belonging to the order procellariiformes and the family Procellariidae namely Cape Petrel *Daption capense* Barau's Petrel *Pterodroma baraui* Wedge-tailed Shearwater *Ardenna pacifica* Short-tailed Shearwater *Ardenna tenuirostris* Flesh-footed Shearwater *Ardenna carneipes* Streaked Shearwater *Calonectris leucomelas* Cory's Shearwater *Calonectris borealis* Tropical Shearwater *Puffinus bailloni* Persian Shearwater *Puffinus persicus* Jouanin's Petrel *Bulweria fallax* are recorded in India.

Flesh-footed Shearwateris the most common seabird in west coast (Chandran *et al.,* 2011, Karuthedathu *et al*., 2013, Palot, 2008). Praveen *et al.* (2011) reported Wedge-tailed Shearwater from the coast of Kannur on May 28, 2011. Karuthedathu *et al.* (2013) reported

Streaked Shearwater from Indian Coast. Sashikumar *et al.* (2011) reported Persian Shearwater from Indian coast. The Jouanin's Petrel was recorded by Karuthedathu *et al.* (2012), Sashikumar *et al.* (2011), Robertson (1995), and Rahmani (2012). No recent records are avalibale for the other species.

Three species belonging to the order Suliformes and the family Fregatidae namely Lesser Frigatebird *Fregata ariel* Great Frigatebird *Fregata minor* Christmas Frigatebird *Fregata andrewsi* are recorded in India. Karuthedathu *et al.* (2015) recorded Lesser Frigatebird and Christmas Frigatebird from east and west coast of India.

Three species belonging to the order Suliformes and the family Sulidae namely Red-footed Booby *Sula sula* Brown Booby *Sula leucogaster* Masked Booby *Sula dactylatra*are recorded in India. Karuthedathu *et al.* (2012) and Sashikumar *et al.* (2011) reported Masked Booby as one of the most frequent windblown species. Jamalabad (2013) recorded Brown Booby while Karmakar (2011) reported Red-footed Booby.

37 species belonging to the order charadriiformes and the family Laridae namely Brown Noddy *Anous stolidus* Lesser Noddy *Anous tenuirostris* Black Noddy *Anous minutus* Common White Tern *Gygis alba* Indian Skimmer *Rynchops albicollis* Little Gull *Hydrocoloeus minutus* Sabine's Gull *Xema sabini* Black-legged Kittiwake *Rissa tridactyla* Slender-billed Gull *Larus genei* Brown-headed Gull *Larus brunnicephalus* Black-headed Gull *Larus ridibundus* Franklin's Gull *Larus pipixcan* Pallas's Gull *Larus ichthyaetus* Sooty Gull *Larus hemprichii* Mew Gull *Larus canus Lesser Black-backed Gull Larus fuscus* Caspian Gull *Larus cachinnans* Arctic Herring Gull *Larus smithsonianus* Sooty Tern *Onychoprion fuscatus* Bridled Tern *Onychoprion anaethetus* Little Tern *Sternula albifrons* Saunders's Tern *Sternula saundersi* Common Gull-billed Tern *Gelochelidon nilotica* Caspian Tern *Hydroprogn ecaspia* Whiskered Tern *Chlidonias hybrid* White-winged Tern *Chlidonias leucopterus* Black Tern *Chlidonias niger* River Tern *Sterna aurantia* Roseate Tern *Sterna dougallii* Black-naped Tern *Sterna sumatrana* Common Tern *Sterna hirundo* White-cheeked Tern *Sterna repressa* Arctic Tern *Sterna paradisaea* Black-bellied Tern *Sterna acuticauda* Lesser Crested Tern *Thalasseus bengalensis* Sandwich Tern *Thalasseus sandvicensis* and Greater Crested Tern *Thalasseus bergii* are recorded in India.

Praveen (2013) recorded Bridled Terns, Sooty Terns (wind-blown species to the coasts-Karuthedathu *et al.,* 2012), Brown Noddy, Great Crested Tern, Lesser Crested Tern, Sandwich Tern, Common Terns, Little tern, Whiskered tern and Gull-billed Terns, Brown-headed Gull, Black-headed Gull, Pallas's Gulls and Lesser Black-backed Gulls from Kerala.

Five species belonging to the order charadriiformes and the family Stercorariidae namely Long-tailed Jaeger *Stercorarius longicaudus* Arctic Jaeger *Stercorarius parasiticus* Pomarine Jaeger *Stercorarius pomarinus* South Polar Skua *Catharacta maccormicki* Brown Skua *Catharacta Antarctica* are recorded in India. Praveen (2013) recorded Parasitic Jaeger S. parasiticus as the most common Jaeger species, with most sightings during September and April along with Pomarine Jaeger S. pomarinus from the Karnataka and Kerala coasts. Praveen *et al*., 2013 and Praveen (2013) confirmed the presence of South Polar Skua *S. maccormicki* from the Thiruvananthapuram coast.

Of the 72 species of pelagic birds, 15 species of birds breed in Indian Territories while other species of birds are non-breeder to India. Birds belonging to phaethontiformes and suliformes are truly pelagic in habitat. In general, all these truly pelagic birds are sighted in poor numbers.

Table 1. Pelagic birds of India

Sl. No.	Order	Family	Common Name	Scientific Name
1	Phaethontiformes	Phaethontidae	Red-billed Tropicbird	*Phaethon aethereus*
2	Phaethontiformes	Phaethontidae	Red-tailed Tropicbird	*Phaethon rubricauda*
3	Phaethontiformes	Phaethontidae	White-tailed Tropicbird	*Phaethon lepturus*
4	Gaviiformes	Gaviidae	Red-throated Diver	*Gavia stellata*
5	Gaviiformes	Gaviidae	Black-throated Diver	*Gavia arctica*
6	Procellariiformes	Oceanitidae	Wilson's Storm-petrel	*Oceanites oceanicus*
7	Procellariiformes	Oceanitidae	White-faced Storm-petrel	*Pelagodroma marina*
8	Procellariiformes	Oceanitidae	Black-bellied Storm-petrel	*Fregetta tropica*
9	Procellariiformes	Hydrobatidae	Band-rumped Storm-petrel	*Hydrobates castro*
10	Procellariiformes	Hydrobatidae	Swinhoe's Storm-petrel	*Hydrobates monorhis*
11	Procellariiformes	Procellariidae	Cape Petrel	*Daption capense*
12	Procellariiformes	Procellariidae	Barau's Petrel	*Pterodroma baraui*
13	Procellariiformes	Procellariidae	Wedge-tailed Shearwater	*Ardenna pacifica*
14	Procellariiformes	Procellariidae	Short-tailed Shearwater	*Ardenna tenuirostris*
15	Procellariiformes	Procellariidae	Sooty Shearwater	*Ardenna grisea*
16	Procellariiformes	Procellariidae	Flesh-footed Shearwater	*Ardenna carneipes*
17	Procellariiformes	Procellariidae	Streaked Shearwater	*Calonectris leucomelas*
18	Procellariiformes	Procellariidae	Cory's Shearwater	*Calonectris borealis*
19	Procellariiformes	Procellariidae	Tropical Shearwater	*Puffinus bailloni*
20	Procellariiformes	Procellariidae	Persian Shearwater	*Puffinus persicus*

Sl. No.	Order	Family	Common Name	Scientific Name
21	Procellariiformes	Procellariidae	Bulwer's Petrel	*Bulweria bulwerii*
22	Procellariiformes	Procellariidae	Jouanin's Petrel	*Bulweria fallax*
23	Suliformes	Fregatidae	Lesser Frigatebird	*Fregata ariel*
24	Suliformes	Fregatidae	Great Frigatebird	*Fregata minor*
25	Suliformes	Fregatidae	Christmas Island Frigatebird	*Fregata andrewsi*
26	Suliformes	Sulidae	Abbott's Booby	*Papasula abbotti*
27	Suliformes	Sulidae	Red-footed Booby	*Sula sula*
28	Suliformes	Sulidae	Brown Booby	*Sula leucogaster*
29	Suliformes	Sulidae	Masked Booby	*Sula dactylatra*
30	Charadriiformes	Stercorariidae	Long-tailed Skua	*Stercorarius longicaudus*
31	Charadriiformes	Stercorariidae	Arctic Skua	*Stercorarius parasiticus*
32	Charadriiformes	Stercorariidae	PomarineSkua	*Stercorarius pomarinus*
33	Charadriiformes	Stercorariidae	South Polar Skua	*Stercorarius maccormicki*
34	Charadriiformes	Stercorariidae	Brown Skua	*Stercorarius antarcticus*
35	Charadriiformes	Laridae	Brown Noddy	*Anous stolidus*
36	Charadriiformes	Laridae	Lesser Noddy	*Anous tenuirostris*
37	Charadriiformes	Laridae	Black Noddy	*Anous minutus*
38	Charadriiformes	Laridae	White Tern	*Gygis alba*
39	Charadriiformes	Laridae	Indian Skimmer	*Rynchops albicollis*
40	Charadriiformes	Laridae	Black-legged Kittiwake	*Rissa tridactyla*
41	Charadriiformes	Laridae	Sabine's Gull	*Xemasabini*
42	Charadriiformes	Laridae	Slender-billed Gull	*Chroicocephalus genei*
43	Charadriiformes	Laridae	Brown-headed Gull	*Chroicocephalus brunnicephalus*
44	Charadriiformes	Laridae	Black-headed Gull	*Chroicocephalus ridibundus*
45	Charadriiformes	Laridae	Little Gull	*Hydrocoloeus minutus*
46	Charadriiformes	Laridae	Franklin's Gull	*Leucophaeus pipixcan*
47	Charadriiformes	Laridae	White-eyed Gull	*Ichthyaetus leucophthalmus*
48	Charadriiformes	Laridae	Sooty Gull	*Ichthyaetus hemprichii*
49	Charadriiformes	Laridae	Pallas's Gull	*Ichthyaetus ichthyaetus*
50	Charadriiformes	Laridae	Mew Gull	*Larus canus*
51	Charadriiformes	Laridae	Lesser Black-backed Gull	*Larus fuscus*
52	Charadriiformes	Laridae	Caspian Gull	*Larus cachinnans*

Sl. No.	Order	Family	Common Name	Scientific Name
53	Charadriiformes	Laridae	Mongolian Gull	*Larus smithsonianus mongolicus*
54	Charadriiformes	Laridae	Sooty Tern	*Onychoprion fuscatus*
55	Charadriiformes	Laridae	Bridled Tern	*Onychoprion anaethetus*
56	Charadriiformes	Laridae	Little Tern	*Sternula albifrons*
57	Charadriiformes	Laridae	Saunders's Tern	*Sternula saundersi*
58	Charadriiformes	Laridae	Gull-billed Tern	*Gelochelidon nilotica*
59	Charadriiformes	Laridae	Caspian Tern	*Hydroprogne caspia*
60	Charadriiformes	Laridae	Whiskered Tern	*Chlidonias hybrida*
61	Charadriiformes	Laridae	White-winged Tern	*Chlidonias leucopterus*
62	Charadriiformes	Laridae	Black Tern	*Chlidonias niger*
63	Charadriiformes	Laridae	River Tern	*Sterna aurantia*
64	Charadriiformes	Laridae	Roseate Tern	*Sterna dougallii*
65	Charadriiformes	Laridae	Black-naped Tern	*Sterna sumatrana*
66	Charadriiformes	Laridae	Common Tern	*Sterna hirundo*
67	Charadriiformes	Laridae	White-cheeked Tern	*Sterna repressa*
68	Charadriiformes	Laridae	Arctic Tern	*Sterna paradisaea*
69	Charadriiformes	Laridae	Black-bellied Tern	*Sterna acuticauda*
70	Charadriiformes	Laridae	Lesser Crested Tern	*Thalasseus bengalensis*
71	Charadriiformes	Laridae	Sandwich Tern	*Thalasseus sandvicensis*
72	Charadriiformes	Laridae	Greater Crested Tern	*Thalasseus bergii*

Table 2. Status of Pelagic birds of India

Sl. No.	English and scientific name	Status	Habitat	Breeding status	Records
1	Red-billed Tropicbird *Phaethon aethereus*	Rare	Pelagic	Non-breeder	West coast
2	Red-tailed Tropicbird *Phaethon rubricauda*	Rare	Pelagic	Breeder (in Nicobar)	Nicobar
3	White-tailed Tropicbird *Phaethon lepturus*	Rare	Pelagic	Non-breeder	East coast
4	Red-throated Diver *Gavia stellata*	-	-	-	No recent record
5	Black-throated Diver *Gavia arctica*	Rare	Less partially pelagic	Non-breeder	Hariyana and Assam
6	Wilson's Storm-petrel *Oceanites oceanicus*	Rare	Pelagic	Non-breeder	Laccadives, West coast, Indo-Sri lankan coast

Sl. No.	English and scientific name	Status	Habitat	Breeding status	Records
7	White-faced Storm-petrel *Pelagodroma marina*	Rare	Pelagic	Non-breeder	West coast
8	Black-bellied Storm-petrel *Fregetta tropica*	Rare	Pelagic	Non-breeder	West coast
9	Band-rumped Storm-petrel *Hydrobates castro*	-	-	-	No recent record
10	Swinhoe's Storm-petrel *Hydrobates monorhis*	Rare	Pelagic	Non-breeder	East coast
11	Cape Petrel *Daption capense*	Rare	Pelagic	Non-breeder	Indo-Sri Lankan Coast
12	Barau's Petrel *Pterodroma baraui*	Rare	Pelagic	Non-breeder	Indo-Sri Lankan Coast, Laccadives
13	Wedge-tailed Shearwater *Ardenna pacifica*	Rare	Pelagic	Non-breeder	Laccadives, West coast
14	Short-tailed Shearwater *Ardenna tenuirostris*	-	-	-	No recent record
15	Sooty Shearwater *Ardenna grisea*	-	-	-	No recent record
16	Flesh-footed Shearwater *Ardenna carneipes*	Rare	Pelagic	Non-breeder	Laccadives, Eest coast
17	Streaked Shearwater *Calonectris leucomelas*	Rare	Partially Pelagic	Non-breeder	Indo-Sri lankan Coast, East Coast
18	Cory's Shearwater *Calonectris borealis*	-	-	-	No recent record
19	Tropical Shearwater *Puffinus bailloni*	-	-	-	No recent record
20	Persian Shearwater *Puffinus persicus*	Rare	Pelagic	Non-breeder	East coast
21	Bulwer's Petrel *Bulweria bulwerii*	Rare	Pelagic	Non-breeder	East coast
22	Jouanin's Petrel *Bulweria fallax*	Rare	Pelagic	Non-breeder	East coast, West Coast, Laccadives
23	Lesser Frigatebird *Fregata ariel*	Rare	Pelagic	Non-breeder	East coast, West coast
24	Great Frigatebird *Fregata minor*	Rare	Pelagic	Non-breeder	East coast, West coast
25	Christmas Island Frigatebird *Fregata andrewsi*	Very rare	Pelagic	Non-breeder	East coast, West coast
26	Abbott's Booby *Papasula abbotti*	-	-	-	No recent record
27	Red-footed Booby *Sula sula*	Very rare	Pelagic	Non-breeder	West coast
28	Brown Booby *Sula leucogaster*	Very rare	Pelagic	Non-breeder	West coast
29	Masked Booby *Sula dactylatra*	Rare	Pelagic	Non-breeder	Laccadives, West Coast
30	Long-tailed Skua *Stercorarius longicaudus*	-	-	-	No recent record
31	Arctic Skua *Stercorarius parasiticus*	Rare	Partially Pelagic	Non-breeder	West Coast, East Coast

Sl. No.	English and scientific name	Status	Habitat	Breeding status	Records
32	Pomarine Skua *Stercorarius pomarinus*	Rare	Partially Pelagic	Non-breeder	West coast
33	South Polar Skua *Stercorarius maccormicki*	Rare	Partially Pelagic	Non-breeder	West coast
34	Brown Skua *Stercorarius antarcticus*	Rare	Partially Pelagic	Non-breeder	West coast, Indo-Sri lankan Coast
35	Brown Noddy *Anous stolidus*	Rare	Pelagic	Breeder (in Laccadives)	Laccadives, Andamans and Nicobar
36	Lesser Noddy *Anous tenuirostris*	-	-	-	No recent record
37	Black Noddy *Anous minutus*	Rare	Pelagic	Non-breeder	Laccadives
38	White Tern *Gygis alba*	Rare	Pelagic	Non-breeder	No recent record
39	Indian Skimmer *Rynchops albicollis*	Common	Less partially pelagic	Non-breeder	East Coast, West Coast, Inland
40	Black-legged Kittiwake *Rissa tridactyla*	-	-	-	No recent record
41	Sabine's Gull *Xema sabini*	-	-	-	No recent record
42	Slender-billed Gull *Chroicocephalus genei*	Rare	Partially Pelagic	Non-breeder	East Coast, West Coast
43	Brown-headed Gull *Chroicocephalus brunnicephalus*	Common	Partially Pelagic	Non-breeder	Laccadives, West coast
44	Black-headed Gull *Chroicocephalus ridibundus*	Common	Partially Pelagic	Non-breeder	Laccadives, West coast
45	Little Gull *Hydrocoloeus minutus*	Rare	Less partially pelagic	Non-breeder	Coastal and Inland waters
46	Franklin's Gull *Leucophaeus pipixcan*	-	-	-	No recent record
47	White-eyed Gull *Ichthyaetus leucophthalmus*	-	-	-	No recent record
48	Sooty Gull *Ichthyaetus hemprichii*	Rare	Partially Pelagic	Non-breeder	East Coast
49	Pallas's Gull *Ichthyaetus ichthyaetus*	Less common	Partially Pelagic	Non-breeder	East Coast, west coast
50	Mew Gull *Larus canus*	Rare		Non-breeder	No recent record
51	Lesser Black-backed Gull *Larus fuscus*	-	-	-	No recent record
52	Caspian Gull *Larus cachinnans*	Less common	Less partially pelagic	Non-breeder	Inlands, East Coast, West Coast
53	Mongolian Gull *Larus smithsonianus mongolicus*	-	-	-	No recent record
54	Sooty Tern *Onychoprion fuscatus*	Common	Partially Pelagic	Breeder (in Vengula Rocks, Laccadives)	west coast

Sl. No.	English and scientific name	Status	Habitat	Breeding status	Records
55	Bridled Tern *Onychoprion anaethetus*	Common	Partially Pelagic	Breeder (in Vengula Rocks)	west coast
56	Little Tern *Sternula albifrons*	Common	Less partially pelagic	Breeder	Inlands, East Coast, West Coast
57	Saunders's Tern *Sternula saundersi*	Common	Less partially pelagic	Breeder (unconfirmed)	Coastal and Inland waters
58	Gull-billed Tern *Gelochelidon nilotica*	Common	Less partially pelagic	Breeder (in Bengal, Orissa)	East coast, West coast
59	Caspian Tern *Hydroprogne caspia*	Common	Less partially pelagic	Breeder (in Gujarat)	East coast, West coast
60	Whiskered Tern *Chlidonias hybrida*	Common	Less partially pelagic	Breeder (in kashmir, Asssam)	Inlands, East Coast, West Coast
61	White-winged Tern *Chlidonias leucopterus*	Common	Less partially pelagic	Non-breeder	Inlands, East Coast, West Coast
62	Black Tern *Chlidonias niger*	-	-	-	No recent record
63	River Tern *Sterna aurantia*	Common	Non-pelagic	Breeder	Almost all parts of India
64	Roseate Tern *Sterna dougallii*	Less common	Less partially pelagic	Breeder (in offshore Islands)	Andamans and Nicobar
65	Black-naped Tern *Sterna sumatrana*	-	-	-	No recent record
66	Common Tern *Sterna hirundo*	very common	Non-pelagic	Breeder (in ladakh)	Inlands, East Coast, West Coast
67	White-cheeked Tern *Sterna repressa*	Common	Less partially pelagic	Breeder (in Vengula Rocks)	Inlands, East Coast, West Coast
68	Arctic Tern *Sterna paradisaea*	very common	-	-	No recent record
69	Black-bellied Tern *Sterna acuticauda*	very common	Less partially pelagic	Breeder	Almost all parts of India
70	Lesser Crested Tern *Thalasseus bengalensis*	Common	Partially Pelagic	Breeder (in Laccadives)	Esatcosat, west coast
71	Sandwich Tern *Thalasseus sandvicensis*	Less common	Partially Pelagic	Non-breeder	east coast, west coast
72	Greater Crested Tern *Thalasseus bergii*	Common	Partially Pelagic	Breeder (in offshore Islands)	East coast, west coast

CONSERVATION AND MANAGEMENT

The pelagic birds of India, besides sea/ocean, exploits habitats like mangroves (covers about 6,749km and situated in East Coast (about 4700km^2), West Coast (about 850 km^2), and Andaman and Nicobar Islands about (1190 km^2) with Lakshadweep atoll), coral Reefs (occurs in Gulf of Kachchh and Lakshadweep in Arabian Sea, Gulf of Mannar, Andaman and Nicobar Islands in Bay of Bengal, off-shore reef in Malvan, Maharashtra), coastal sand dunes (a poorly documented ecosystem), mudflats (covering an area of more than 38,000 km^2), salt Marshes (covers 1696.3796 sq. km), and seagrass beds (along the Gulf of Mannar and Palk Bay, in the lagoons of islands from Lakshadweep and Andaman and Nicobar (Bay of Bengal). Besides serving as a habitat for birds, mangroves play a major role in carbon sequestration. In order to protect the oceanic birds and the above mentioned habits, the Government of India has already formed a National network of 38 Marine and Coastal Protected Areas (MCPAs) that forbid extractive uses and employ sustainable management practices. Besides, there are another 100 PAs as National Parks or Wildlife Sanctuaries. However, lack of funds, lack of man power, and inadequate coordination between public and policy makers adversely affect the above system. However, potential sites like Bhusandpur and Tinimuthan, Burnt Island (Bandra) Vengurla Rocks, Mahul-Sewree Creek, Thane Creek, Point Calimere, Great Vedaranyam Swamp, Chilika Lake, Gulf of Mannar Biosphere Reserve, and Pulikat Bird Sanctuary are brought under the above scheme and well protected to conserve the oceanic birds.

Sutherland *et al.* (2012) identified 45 threats faced by the shorebirds around the world and placed under three categories: natural (volcanoes and cyclone), current anthropogenic (habitat conversion, climate change) and future issues (microplastics, global hydro security and changes in sedimentation rates). However, in India, threats can be largely linked to habitat loss. The human population increase has considerably reduced the potential habitats available for shorebirds. Loss of key habitats, particularly stopover habitats for migrants on the migratory pathway and breeding ground for migrants, has significant consequences for a number of pelagic species. As areas become less, overcrowding, competition, and increased risk of disease transmission among shorebirds will be inevitable on the existing habitats.

Disturbance from human activities has a high energetic cost to shorebirds and may compromise their capacity to build sufficient energy reserves to undertake migration (Goss-Custard *et al.,* 2006; Weston *et al.*, 2012). Hence, even a small disturbance capable of altering a habitat unusable for birds can exacerbate pelagic bird population declines, as unusable habitat is equivalent to habitat loss. Besides, climate change has the potential to affect migratory shorebirds and their habitats by reducing the extent of coastal and inland wetlands or through a poleward shift in the range of many species (Chambers *et al.*, 2005; Iwamura *et al.*, 2013).

Overharvesting of marine resources can lead to decreased productivity and changes in prey distribution and availability (MacKinnon *et al.*, 2012). Hence, controlled harvesting should be introduced for the conservation of oceanic birds. Further, accidental killing of

pelagcic birds requires further investigation.

CONCLUSION

India harbours around 72 species of pelagic birds belonging to five orders and nine families. Of the 72 species, 15 breed in Indian Territories while the rest are mere migrants/vagrants to India. Birds belonging to phaethontiformes and suliformes are truly pelagic in habitat and often sighted in poor numbers. Studies on ecological requirements of the pelagic birds are the immediate need for the conservation and management of these species in India.

REFERENCES

Abdulali, H., 1970. A catalogue of the birds in the collection of the Bom- bay Natural History Society-7. Scolopacinae (part), Phalaropinae, Ro- stratulidae, Recurvirostridae, Dromadidae, Burhinidae, Glareolidae, Stercorariidae, Laridae. *J. Bombay Nat. Hist. Soc.*, **67**(2): 279–298.

Ali, S., and Ripley, S. D., 1983. *Handbook of the birds of India and Pakistan together with those of Bangladesh, Nepal, Bhutan and Sri Lanka*. Compact ed. Delhi: Oxford University Press.

Baidya, P., Bhagat, M., Dharwadkar, O. and Gauns, H., 2017. Seabirds of Goa, India: Recent updates. *Indian BIRDS,* **13**(1): 8–17.

Balachandran, S., 1992. Occurrence of White or Longtailed Tropic-bird Phaethon lepturus on the South-East coast of India. *J. Bombay Nat. Hist. Soc.*, **88**(3): 441–442.

Chambers. L.E., Deveny, C.A., Congdon, B.C., Dunlop, N., Woehler, E.J., and Dann, P., 2011. Observed and predicted effects of climate on Australian seabirds. *Emu*, **111**: 235-257.

Chandran, A.V., Praveen, J., Sreenivasan, P.P., Nameer, P.O. and Dilip, K.G. 2011. Swinhoe's Storm-Petrel *Oceanodromamonorhis* and other pelagic birds from the Thrissur coast, Kerala. *Indian Birds,* **7**(*3*): 73–74.

Daniels, R. J. R. 1992. Island biogeography and the birds of the Lakshadweep Archipelago, Indian Ocean. *J. Bom. Nat. Hist. Soc.,* **88**(3): 320–328.

delHoyo, J., Elliott, A. and Sargatal, J. (Eds.), 1992. *Handbook of the birds of the world*. Volume 1. Ostrich to Ducks. Vol 1. 1st ed. Barcelona: Lynx Edicions.

Goss-Custard, J.D., Triplet, P., Sueur, F. and West, A.D., 2006. Critical thresholds of disturbance by people and raptors in foraging wading birds. *Biological Conservation*, **127**: 88-97.

Harrison, P., 1983. *Seabirds: An identification guide*. 1st ed. London and Wellington: Croom Helm Limited and A.H. and A.W. Reed Ltd.

Hume, A. O., 1876. The Laccadives and the West Coast. *Stray Feathers,* **IV** (4,5 and 6): 413–483.

Hume, A. O., 1877. Notes. *Stray Feathers,* **V**(5 and 6): 495–502.

Iwamura, T., Possingham, H.P., Chadès, I., Minton, C., Murray, N.J., Rogers, D.I., Treml, E.A. and Fuller, R.A., 2013. Migratory connectivity magnifies the consequences of habitat loss from sea-level rise for shorebird populations. *Proceedings of the Royal Society Biological Sciences*, **280**: 20130325.

Jones, A. E., 1922. Occurrence of the Blackthroated Diver Colymbusarcti- cus in India. *J. Bombay Nat. Hist. Soc.,* **28**(4): 1134.

Karmakar, S., Ghosh, S., Bhadra, A. and Sen, S., 2011. Birds of India (*http://www.kolkatabirds.com*): Red-footed Booby - a rare vagrant 2011 at *http://www.kolkatabirds.com/redfootedbooby.htm*

Karuthedathu, D., James, D., Sasidevan, A., Moghul, M., Parab, P., Davidson, S. S., Manickam, S., Rao, V. and Vineeth M., 2015. A compilation of frigatebird sightings from 2014, including Christmas Island FrigatebirdFregataandrewsi. *Indian BIRDS*,

10(5): 115–118.

Karuthedathu, D., Palot, M.J., Praveen, J. Sreenivasan, P.P. and Uthaman, K.V., 2013. Streaked Shearwater *Calonectricsleucomelas* from Kannur coast, Kerala. *Indian Birds,* **8**(2): 44–45.

Karuthedathu, D., Praveen, J. and Palot, M.J., 2012. Recent trends in marine bird monitoring in India. *J. Bom. Nat. Hist. Soc.,* **109**(1 and 2): 53–59

Lainer, H., 2003. Terns of the Vengurla Rocks, a review and update. *J. Bombay Nat. Hist. Soc.* **100**(1): 126–135.

MacKinnon, J., Verkuil, Y.I. and Murray, N., 2012 IUCN situation analysis on East and Southeast Asian intertidal habitats, with particular reference to the Yellow Sea (including the Bohai Sea). Occasional Paper of the IUCN Species Survival Commission No. 47. IUCN, Gland, Switzerland and Cambridge, UK. ii + 70 pp.

Madsen, S. T., 1990. Skuas Stercorarius sp. on the west coast. *J. Bombay Nat. Hist. Soc*., **87** (2): 297.

Mathew, D. and Ambedkar, V., 1964. A birdwatching trip to the Laccadive Islands. NLBW 4 (7): 2–4.

Mohan, R.S.L., 1989. Some observations on the marine mammals and marine birds. *CMFRI Bulletin*, **43**: 195–199.

Palot, J., 2003. Occurrence of Redbilled Tropic Bird, Phaethon aethereus at Kozhikode, Kerala. *Malabar Trogon*, **1**(4): 2–3.

Palot, M. J., 2011. White-tailed Tropicbird Phaethon lepturus from Kerala, South India. *Indian BIRDS*, **7**(3): 75

Palot, M.J., 2008. Occurrence of Flesh-footed Shearwater *Puffinus carneipes* on the Kozhikode coast, Kerala. *Indian Birds,* **4**(2): 73

Pande, S. Sant, N. R., Ranade, S.D., Pednekar, S.N., Mestry, P.G., Kharat, S., Sanjay, S. and Deshmukh, V., 2007. An ornithological expedition to the Lakshadweep archipelago: Assessment of threats to pelagic and other birds and recommendations. *Indian Birds,* **3**(1): 2–12.

Phillips, W. W. A., 1955. Wilson's Petrel [Oceanitesoceanicus (Kuhl)] in Indo–Ceylon waters, with special reference to the 1954 southward migration. *J. Bombay Nat. Hist. Soc*., **53** (1): 132–133.

Praveen, J., Karuthedathu, D., Prince, M., Palot, M.I. and Deloc, S., 2013. Identification of South Polar Skuas *Catharacta maccormicki* in the Arabian Sea and Indian Ocean. *Birding ASIA,* **19**: 83–88.

Praveen J., 2011. A review of pelagic bird records in Sea Swallow from the off-shore waters of Kerala. *Malabar Trogon,* **9**(1 and 2): 7–10.

Praveen, J., Karuthedathu, D., Palot, M., Prince, M. and Meppayur, S., 2011. Significant pelagic bird sightings from the off-shore waters of the Malabar coast, southern India. *Indian Birds,* **7**(3): 66–69.

Rahmani, A.R., 2012. *Threatened Birds of India* Oxford University Press, XVI + 864 pages.

Rasmussen, P. C. and Anderton, J. C., 2005. *Birds of South Asia: the Ripley guide*. 2 vols. 1st ed. Washington, D.C. and Barcelona: Smithsonian Institution and Lynx Edicions.

Robertson, A. L. H., 1995. Occurrence of some pelagic seabirds (Procellariiformes) in waters off the Indian subcontinent. *Forktail*, **10**: 129–140 (1994).

Sashikumar, C., Praveen J., Palot, M. J. and Nameer, P. O., 2011. Birds of Kerala: status and distribution. 1st Ed. Kottayam, Kerala: DC Books.

Steijn, L. and Vries, K.d., 2009. Black-throated Loon in Assam, India, in January 2008. *Dutch Birding,* **31**: 301–302

Sutherland, W.J., Alves, J.A., Amano, T., Chang, C.H., Davidson, N.C., Finlayson, C.M., Gill, J.A., Gill, R.E., González, P.M., Gunnarsson, T.G., Kleijn, D., Spray, C.J., Székely, T., and Thompson, D.B.A., 2012. A horizon assessment of current and potential future threats to migratory shorebirds. *Ibis*, **54**: 663-679.

Ticehurst, C. B., 1927. The birds of British Baluchistan. Part III. *J. Bombay Nat. Hist. Soc.*, **32**(1): 64–97

Weston, M.A., McLeod, E.M., Blumstein, D.T. and Guay, P.-J., 2012. A review of flight-initiation distances and their application to managing disturbance to Australian birds. *Emu*, **112**: 269-286.

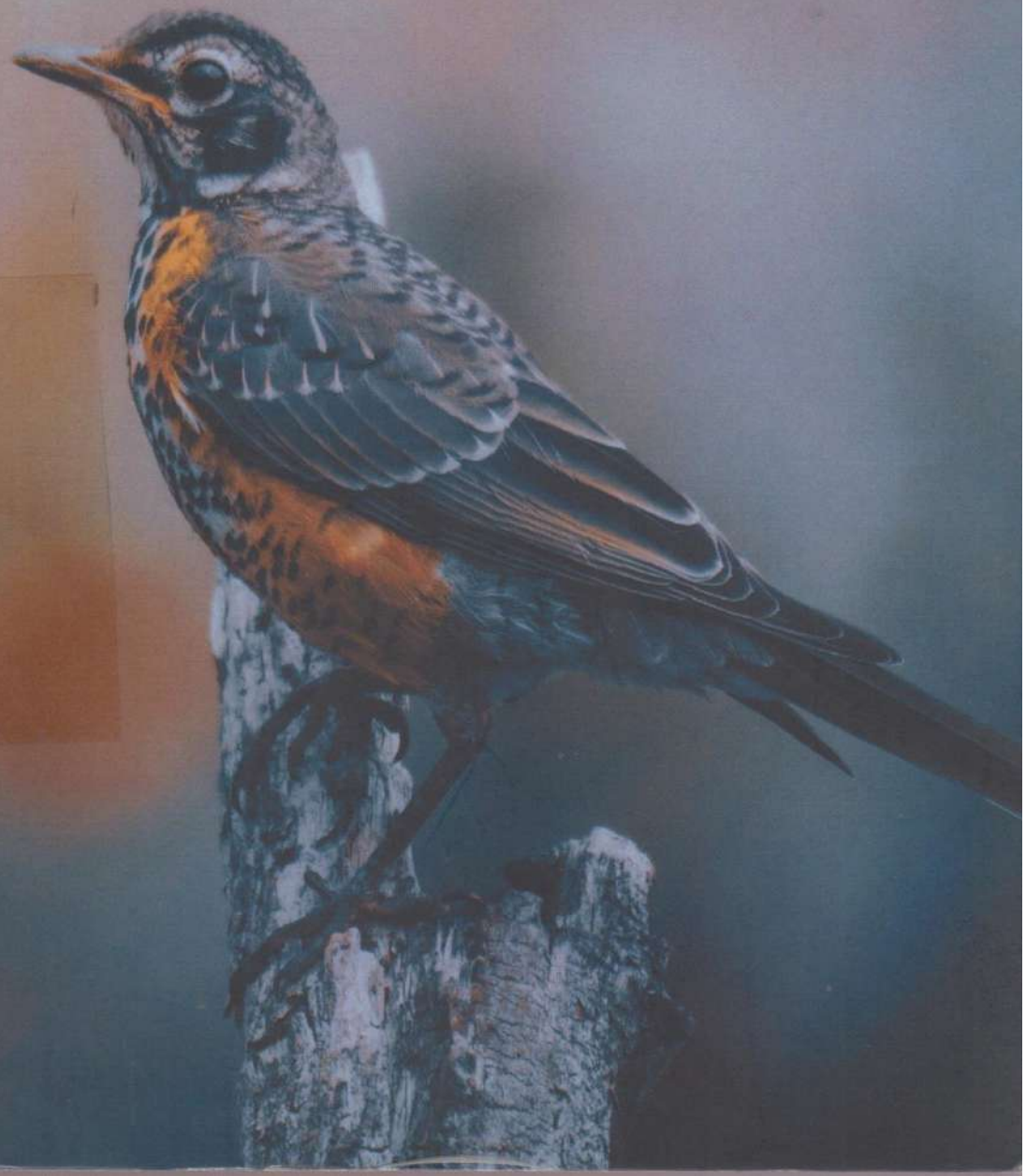
Deep Sea is the largest ecosystem in the planet Earth serves as a vast reservoir of biodiversity. However, it remains unexplored as only 0.0001% of biodiversity documented from this extreme environment. India is endowed with 2.02 million sq. km. area of Exclusive Economic Zone in marine area, of which 60 percent falling under deep sea i.e. above 200 m deep. Zoological Survey of India made a pioneer studies in Indian seas through the oceanographic expeditions of RIMS Investigator since from 1874 to 1926. The book provides the consolidated information of deep sea fauna dealing 4371 faunal species based on the data collected over the period of more than 100 years

ISBN 978-81-8171-569-2

வ. கோகுலா

காக்கைச் சிறகினிலே

பறவைகளின் வண்ணமயமான உலகம்



காக்கைச் சிறகினிலே

Kakkai Siraginile

V. Gokula ©

Kizhakku First Edition: December 2022

200 Pages
Printed in India.

ISBN : 978-93-90958-62-7
Kizhakku - 1297

Kizhakku Pathippagam
177/103, First Floor, Ambal's Building, Lloyds Road,
Royapettah, Chennai - 600 014. Ph: +91-44-4200-9603
Email : support@nhm.in Website : www.nhm.in

kizhakkupathippagam kizhakku_nhm

Author's email id: gokulae@yahoo.com

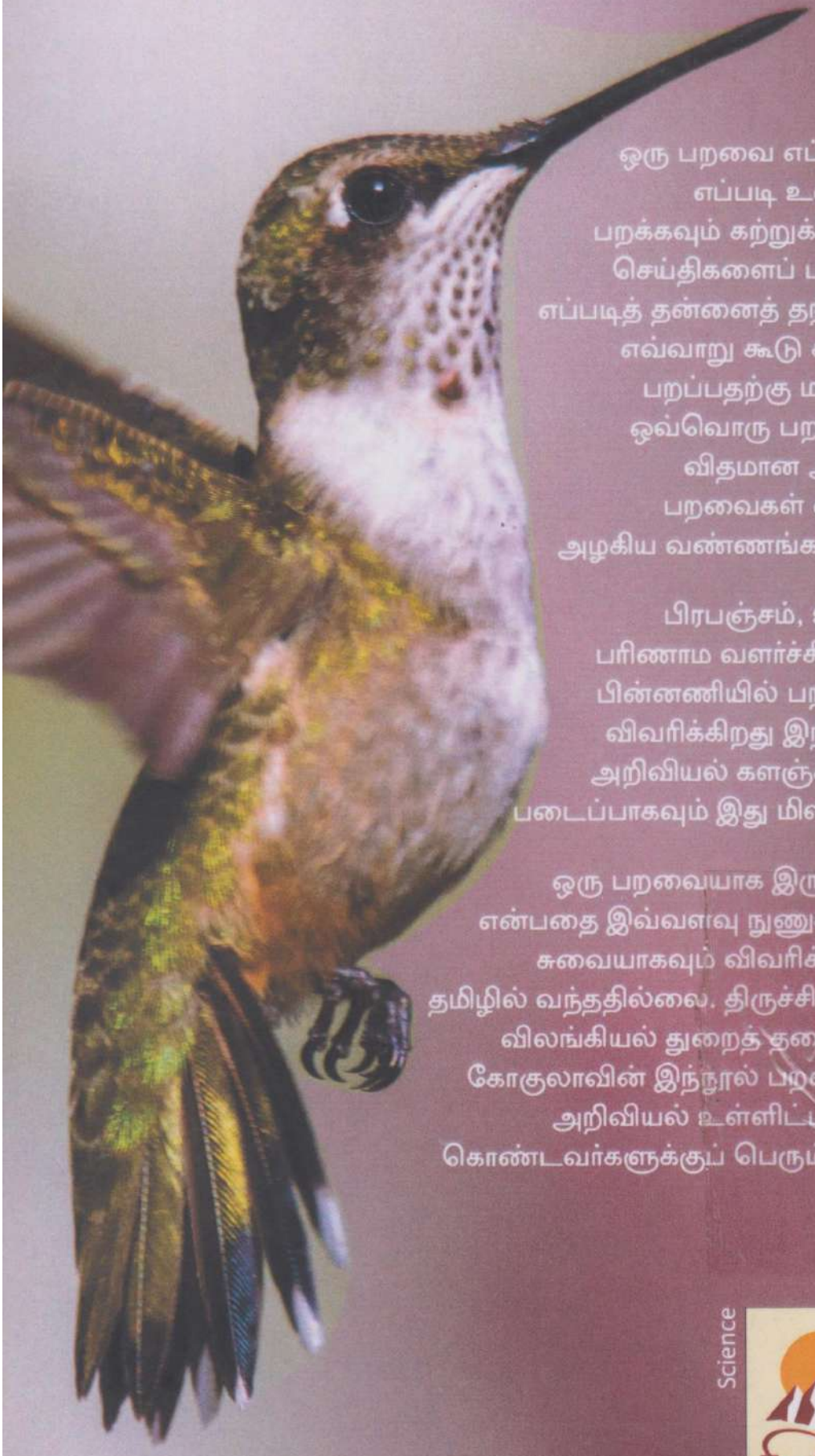
All illustrations, photos and images are for informational purposes only and are copyrighted by their respective owners.

Kizhakku Pathippagam is an imprint of New Horizon Media Private Limited

The views and opinions expressed in this book are the author's own and the facts are as reported by the author, and the publishers are not in any way liable for the same.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without the prior permission of the publishers.

பறவைகளின் வண்ணமயமான உலகுக்குள் நுழைய வேண்டுமா? இதோ ஒரு கையடக்க வழிகாட்டி!



ஒரு பறவை எப்படித் தோன்றுகிறது? எப்படி உண்ணவும் உறங்கவும் பறக்கவும் கற்றுக்கொள்கிறது? எப்படிச் செய்திகளைப் பரிமாறிக்கொள்கிறது? எப்படித் தன்னைத் தற்காத்துக்கொள்கிறது? எவ்வாறு கூடு கட்டுகிறது? இறக்கை பறப்பதற்கு மட்டும்தான் உதவுமா? ஒவ்வொரு பறவைக்கும் ஒவ்வொரு விதமான அலகு இருப்பது ஏன்? பறவைகள் எங்கிருந்து இவ்வளவு அழகிய வண்ணங்களைப் பெறுகின்றன?

பிரபஞ்சம், உயிர்களின் தோற்றம், பரிணாம வளர்ச்சி என்று மிக விரிவான பின்னணியில் பறவைகளின் கதையை விவரிக்கிறது இந்நூல். ஒரே நேரத்தில் அறிவியல் களஞ்சியமாகவும் அழகியல் படைப்பாகவும் இது மிளிர்வதைக் காணலாம்.

ஒரு பறவையாக இருப்பது என்றால் என்ன என்பதை இவ்வளவு நுணுக்கமாகவும் இவ்வளவு சுவையாகவும் விவரிக்கும் இன்னொரு நூல் தமிழில் வந்ததில்லை. திருச்சி தேசியக் கல்லூரியில் விலங்கியல் துறைத் தலைவராகப் பணிபுரியும் கோகுலாவின் இந்நூல் பறவையியல், சூழலியல், அறிவியல் உள்ளிட்ட துறைகளில் ஆர்வம் கொண்டவர்களுக்குப் பெரும் திறப்பாக அமையும்.

ரூ.230

Science



ISBN 978-93-90958-62-7

9 789390 958627

www.nhm.in

ISBN: 978-93-91768-31-7

RECENT TRENDS OF INNOVATIONS IN CHEMICAL AND BIOLOGICAL SCIENCES VOLUME I

EDITOR

DR. BASSA SATYANNARAYANA

MR. MUKUL BARWANT



Bhumi Publishing

FIRST EDITION: 2022

RECENT TRENDS OF INNOVATIONS IN CHEMICAL AND BIOLOGICAL SCIENCES

VOLUME - I

(ISBN: 978-93-91768-31-7)

Edited by

Dr. BASSA SATYANNARAYANA

Assistant Professor

Department of Chemistry,

Govt M.G.M P. G. College, Itarsi, MP-461111

E-mail: satyanarayana.bassa@gmail.com

Mr. MUKUL BARWANT

Assistant Professor

Department of Botany,

Sanjivani Arts Commerce and Science College,

Kopargaon, Ahmednagar, Maharashtra, India

E-mail: mukulbarwant97@gmail.com

Bhumi Publishing

2022

CONTENT

Sr. No.	Book Chapter and Author(s)	Page No.
1.	**ETHNOMEDICINAL PLANTS USED FOR RESPIRATORY DISORDERS IN REASI DISTRICT, JAMMU AND KASHMIR (INDIA)** Tarun Thakur and Bharty Kumar	1 – 6
2.	**INORGANIC METAL OXIDE-POLYMER NANOCOMPOSITES FOR NEAR INFRA-RED (NIR) REFLECTIVE COATING APPLICATIONS** Giable George	7 – 13
3.	**BIOLOGICAL ACTIVITY OF TRADITIONAL INDIAN MEDICINAL PLANTS** D. Gayathri	14 – 48
4.	**ROLE OF SACRED GROVES IN BIODIVERSITY CONSERVATION WITH SPECIAL REFERENCE TO UTTARAKHAND** Satya Raj Singh	49 – 55
5.	**QUALITATIVE EVALUATION OF VARIOUS EXTRACTS OF MEDICINALLY RICH PLANT- *COMMIPHORA MUKUL* RESIN** Shweta Hingwasiya and Shailbala Baghel	56 – 62
6.	**TOXIC EFFECTS OF ENVIRONMENTAL CHEMICAL MIXTURES** Anita Singh	63 – 72
7.	**PHARMACOLOGICAL POTENTIAL OF SELECTED PLANTS OF EUPHORBIACEAE FAMILY** Reena Gami	73 – 78
8.	**PHYTOCHEMISTRY AND APPLICATIONS OF ACTIVE INGREDIENTS OF MEDICINAL PLANTS** Yogesh Chandra Nainwal and Tarun Mohan	79 – 85
9.	**INTRODUCTION TO MEDICINAL CHEMISTRY - AN OVERVIEW** Sarabjot Kaur Makkad	86 – 91

Chapter 3

BIOLOGICAL ACTIVITY OF TRADITIONAL INDIAN MEDICINAL PLANTS

D. GAYATHRI

Department of Zoology, National College, Trichy, Tamil Nadu, India

Corresponing Author E- Mail: gayathridzoo@nct.ac.in

ABSTRACT

Herbal medicines and phytomedicine have been employed in healthcare systems, since ancient times. Various nations, ethnic groups, and cultures from throughout the world have traditionally employed medicinal herbs. Plants are a potential source of therapeutic compounds with great pharmacological value and significant application in the advancement of healthcare. In both developing and developed countries, the use of herbal medicines to treat many human ailments has enormous potential. Numerous indigenous medicinal plant varieties offer protection against a variety of serious ailments. Secondary metabolites from plants are also becoming quite important in the pharmaceutical and nutraceutical sectors. Products made from traditional system of medicinal plants are reasonably priced, have few adverse effects, and pose little danger. In reality, plants deploy secondary metabolites as defense mechanisms. It strengthens human immunity while also providing defense against bacteria, viruses, parasites, and other serious disorders. It recognizes dangerous compounds entering human body from external environment and destroys them. The plants that are historically utilized for illness prevention and treatment are the subject of the current research. In India, there is a large supply of these medicinal plants with a variety of claimed pharmacological effects. This chapter focuses on those indigenous medicinal plants that can provide defense against a range of human illnesses. A sizable portion of the world's population may find this chapter useful in gaining insight about naturally occurring preventative and therapeutic substances in the traditional medicinal plants of India.

KEYWORDS: Medicinal plants, Phytochemicals, Herbal medicine, Pharmacological properties.

INTRODUCTION

Plant-derived therapeutic items are the most popular, accepted, and acknowledged type of medicine in today's human society worldwide. The basic sources of herbal, pharmacological, and nutraceutical formulations are phytocompounds, which are created by plants in a variety of ways from primary metabolites. These plant's therapeutic and nutritional needs are met by a variety of phytomolecules that have specific biological effects on the human organ system. Different plant components are used by people to create phytomedicine, which serves as a

remedy for contemporary cultures, civilizations and society. Different traditional medicinal plants would be the finest alternative source to acquire high-quality and essential herbal formulations for the treatment and prevention of many ailments [1, 3]. Indian medicinal plants have long been considered a viable source for the treatment of several ailments [4]. Ethno botanicals, natural materials, and their derivatives have demonstrated potential efficacy in the treatment of variety of disorders [5]. Consuming fruits, vegetables, ethno medicinal plants, or their products, in a very efficient manner, generates the defenses against many diseases, since medicinal plants are an incredible source of various phytochemicals, including flavonoids, tannins, terpenoids, polyphenols, steroids, alkaloids, glycosides, chlorophyll, carotenoids, proteins, minerals, and vitamins, which have potent antioxidant properties as well as other biological activities [6, 7]. Around the world, more than 80,000 different species of plants are utilized as medicines, and the majority of them are passed down orally from generation to generation. It implies that the foundation of traditional or folklore remedies is the use of medicinal herbs. Traditional medicinal herbs are currently receiving major attention from the mainstream medical community or healthcare delivery system. Many people in underdeveloped or developing nations continue to use traditional medicines as their main source of treatment for a variety of maladies. These indigenous medicinal herbs are widely utilized as a strong source of alternative medicines to treat a variety of medical conditions. The mainstays of the primary healthcare system for humans are the medicinal plants, due to their accessibility, acceptance, compatibility and cost [8, 9]. In order to create safe and effective herbal formulations, medicinal and aromatic plants are important and significant sources of primary and secondary metabolites that are utilized as templates for lead optimization procedures [10].

Numerous medical professionals and researchers frequently suggest using numerous medicinal plant species or their derivatives to gain protection from a variety of health issues due to their curing potential, ease of availability and cost-effectiveness. The plants examined in this chapter have a long history of use as medicines and are abundant in a variety of bioactive compounds. These herbs are extremely effective against a number of life threatening illnesses, including bacterial and viral infections, diabetes, renal and lung cancer [11, 12]. Hundred species of Indian traditional medicinal plants (herbs, shrubs and trees) are being compiled through this chapter and are shown in the accompanying table. These are incredibly powerful for both preventing and curing a variety of illnesses. By using contemporary pharmacological technology and procedures, these medicinal plants can be exploited to create herbal medicines and efficient nutraceuticals.

Table 1: Some Important Indian Traditional Medicinal Plants and Their Healing Properties against Various Human Diseases

Sr. No.	Botanical Name	Family	Common Name	Phytochemical compounds	Ethnomedicinal Uses	Pharmacological Activities
1	*Ocimum sanctum*	Lamiaceae	Holy basil	Phenolics, flavonoids, phenyl propanoids, terpenoids, fatty acid, ursolic acid, apigenin, luteolin, steroids, eugenol, and carvacrol.	It is used for nausea, cold and flu, fever, indigestion, stress, anxiety, earache, bronchitis, malaria, diabetes, asthma, heart disease, snakebite antidote, hepatitis, tuberculosis, genitourinary disorders, migraine, acne, Anti-aging purposes.	Antimicrobial Antioxidant Anti-tussive Anti-inflammatory Anti-diabetic Anti-pyretic Anti-arthritic [13 14]
2	*Azadirachta indica*	Meliaceae	Neem	Phenolic compounds, alkaloids, glycosides, terpenoids, flavonoids, azadirachtin, nimbin, azharon, nimbidol, azadirone, melianol, steroids, and tannins.	This plant parts are used for the treatment of rheumatism, asthma, fever, worm infestations, bacterial infection, tuberculosis, diarrhea, jaundice, dysentery, to promote healing, measles, smallpox, inflamed gums, urinary Diseases.	Antimicrobial Anti-cancer Anti-fertility Anti-inflammatory Anti-malarial Antioxidant Neuro-protective Insect repellent [15]
3	*Mentha piperita*	Lamiaceae	Mint	Flavonoids, carbohydrates, alkaloids, phenols, coumarin, saponin, steroids, essential oils (menthol, menthone, pulegone, Menthofuran) azulenes, cholene, carotenes and tannins.	It is used in indigestion, diarrhea, hyperacidity, anemia, morning sickness, bad breath and gum problem, Irritable bowel syndrome, tuberculosis, bronchitis, eczema, acne, anxiety, Crohn's disease, colitis, gallbladder, liver Complaints.	Antibacterial Antioxidant Anti-inflammatory Anti-pyretic Anti-cancer Anti-parasitic Anti-diarrheal Anti-tussive [16]

4	*Zingiber officinale*	Zingiberaceae	Ginger	Phenolic compounds, flavonoids, steroids, triterpenoids, glycosides, tannins, saponins, proteins, carbohydrates, amino acids and proteins,volatile oil.	This plant is used to treat stomach upset, nausea, vomiting, nose bleeds, rheumatism, coughs, chest congestion, cholera, cold, diarrhea, dropsy, stomachache, and baldness,snakebite and toothache.	Analgesic Anthelmintic Anti-arthritic Anti-cancer Anti-diabetic Anti-hypertensive Antimicrobial Antioxidant [15]
5	*Allium sativum*	Amaryllidaceae	Garlic	Alkaloids, glycosides, saponins, flavonoids, steroids, proteins, carbohydrates, oils, reducing sugars and acidiccompounds.	It is used as natural immunity booster, reduces high blood pressure, diabetes, cardiovascular diseases, and reduces stress, cure nerve problems, skin darkening, and blisteringpurposes.	Antioxidant Anti-cancer Anti-inflammatory Antimicrobial Anti-diabetic Atherosclerosis Anti-hypertensive [13]
6	*Curcuma longa*	Zingiberaceae	Turmeric	Carbohydrates, protein, curcumin, tannins, alkaloids, saponins, flavonoids, terpenoids and cardiac glycosides, coumarins, and steroids.	It is used to cure burns, cuts, improves digestion, dissolves gallstone, relieves arthritis, prevents cancer, helps in Alzheimer, and inhibits bacteria, virus, fungi, and parasites, cures acne, pimples, allergy, andpores.	Antioxidant Antimicrobial Antiseptic Anti-inflammatory Anti-carcinogenic Anti-allergic Anti-diabetic [13]
7	*Allium cepa*	Amaryllidaceae	Onion	Flavonoids, carbohydrates, glycosides, proteins, alkaloids, saponins, acid compounds, reducing sugars, oils and tannins.	It is mainly used for common cold, normalizes blood pressure, prevent diarrhea, inhibits microbial infection, increases appetite, treats diabetes, inhibits cancer cell growth, stimulates respiratory tract,helpful in swollen feet, hair growth	Anti-diabetic, Anti-cancer Antimicrobial Antioxidant Anti-platelet Anti-inflammatory Anti-thrombotic Anti-hypertensive [13]

8	*Spinacia oleracea*	Amaranthaceae	Spinach	Flavonoids, carotenoids, β-carotene, apocyanin, ascorbic acid, proteins, amino acids, steroids, tannins, carbohydrates, anthroquinones, coumarin, and saponins.	It is used in digestion, liver and kidney diseases, diuretic, laxative, inflammation of the lungs, bowels, sore throat, ring worm scabies, constipation, anemia, diabetes, fever, brain and heart disease, urinary infection, gallstones.	Anti-diabetic, Antioxidant Anti-inflammatory Anti-carcinogenic Antimicrobial Protection against Gamma Radiation Hepato-protective [17]
9	*Carica papaya*	Caricaceae	Papaya	Flavonoids, papain, tannins, saponins, alkaloids, phenolic compounds and phytosterols, alkaloids, saponins, and glycosides.	It prevents dengue fever, cancer cell growth, facilitates digestion, menstrual pain, anti- malarial, and helps in IBS, used in skin problems, arthritis, dressing wounds, and cure dyspepsia.	Wound healing Nephro-protective Anti-inflammatory Anthelmintic Antimicrobial Anti-diabetic Analgesic [13]
10	*Actinidia deliciosa*	Actinidiaceae	Kiwi	Flavonoids, polyphenols, anthocyanin, carotenoids, alkaloids, tannin, proteins, triterpenoids, carbohydrate, and minerals.	Kiwi is used for good digestive health, hair growth, and strong bone, in eye disease, pregnancy period, stress, high blood pressure, cancer, to reduce stone in kidney, lower blood Sugar level, and better sleep.	Anti-diabetic Hepato-protective Dermatological Activity Antioxidant Anti-inflammatory Cardio-protective ACE Inhibitor [18]
11	*Camellia sinensis*	Theaceae	Green tea	Flavonoids, tannins, caffeine, polyphenols, boheic acid, theophylline, theobromine, anthocyanins, and gallic acid.	Green tea helps in weight loss and metabolism, lowers blood sugar level, used in heart disease, esophageal cancer, high cholesterol, Alzheimer's and Parkinson's disease, helps in depression, good sleep, tooth decay, to reduce wrinkles and signs of aging.	Antioxidant Anti-carcinogenic Anti-arteriosclerotic Antimicrobial Anti-cancer Anti-diabetic Weight control Anti-hypertensive Cardio-protective [19,20]

12	*Prunus dulcis*	Rosaceae	Almonds	Flavonoids, carotenoid, phenolics, tannins, lignans, anthocyanins, phytosterols, polyphenols, and fatty acids.	Almond has memory improving activities, used for insomnia, headache, respiratory troubles, colic pain and peptic ulcer disease, constipation, enhances glow and fairness of skin, cures hair fall, itching, used in kidney stone, ladder, and strengthening of tooth.	Antioxidant Anti-aging Hepato-protective Memory Improving Anxiolytic Activity Hypoglycemic Anti-inflammatory Immuno-stimulant [21]
13	*Cuminum cyminum*	Apiaceae	Cumin	Alkaloid, coumarin, anthraquinone, flavonoid, glycoside, protein, resin, saponin, tannin and steroid.	It is used against jaundice, lung diseases, nosebleeds, menstrual pains, remedy for colic or diarrhea, digestive problems, stimulates saliva production, excretion of bile, increase production of breast milk, used in menstrual cramp, inhibit formation of tumors, lowers blood sugar, to treat insomnia, fever.	Antimicrobial Anti-inflammatory Antioxidant Anti-diabetic Anti-platelet Anti-cancer Hypotensive Bronchodilatory Anti-amyloidogenic Anti-osteoporotic [13]
14	*Marsilea quadrifolia*	Marsileaceae	Marsilea	Polyphenols, tannins, saponins, flavonoids, steroids, terpenoids, alkaloids, carbohydrates, and proteins.	It is used to treat cold, respiratory troubles, hypertension, insomnia, anemia, in migraine, epilepsy, diarrhea, bronchitis, hepatitis, to treat snake bite, skin diseases, and inflammation, enhances memory, lowers blood sugar.	Anti-tussive Analgesic Anti-diabetic Anti-pyretic Antimicrobial Anti-tumor Anti-inflammatory Hepato-protective Antioxidant [22]

15	*Nigella sativa*	Ranunculaceae	Black cumin	Alkaloids, carboxylic acid, coumarins, phenol, resin, saponin, and steroid, protein, fat, and carbohydrates.	It has been used for the treatment of respiratory problems, digestive tract, and kidney, liver function, cardiovascular system, asthma, inflammatory diseases, externally its oil is used as antiseptic, anesthetic, to stop vomiting, in dropsy, and in treatments of worm and skin eruptions.	Antimicrobial Anti-inflammatory Anti-hyperlipidemic Anti-cancer Anti-diabetic Anti-hypertensive Wound healingactivity Gastro-protective Antioxidant Analgesic [13]
16	*Lactuca sativa*	Asteraceae	Lettuce	Phenols, flavonoids, triterpenoid, saponins, anthocyanin, β-carotene, ascorbic acid, riboflavin, niacin, carotine, iodine, andfluorine.	The milky leaves of the plant contain 'lactucarium' is used in medicine for its anodyne, digestive, diuretic, hypnotic, narcotic, sedative, to treat insomnia, anxiety, neuroses, dry cough, pain, drowsiness, preventsmicrobial attacks.	Hypoglycaemicactivity Anxiolytic effect Sedative Effect Anti-inflammatory Antioxidant Anti-aging Antimicrobial [23]
17	*Citrus limon*	Rutaceae	Lemon	Alkaloids, flavonoids, limonoids, steroids, terpenoids, carotenoids, tannic acids and phenolic compound.	Lemon is active against bacteria, reduces inflammation, against fever, prevents scurvy, ulcer, urinary diseases, an antidote against poison, prevents bad breath, body odor, lowers blood pressure, vomiting, liver disorder, enhances immunity, for glowing skin.	Antioxidant Anti-scorbutic Anti-migraine Diuretic Anti-inflammatory Antimicrobial Anti-carcinogenic Anti-pyretic Hypertension Antidote Anti-ulcer [24]

18	*Piper nigrum*	Piperaceae	Black pepper	Alkaloids, flavonoid, cardiac glycosides, piperine, piperatine, piperidine, protein, carbohydrats, essential oils, and tannins.	It prevents asthma, arthritis, bronchitis, used in infection that causes diarrhea, headache, stuffy nose, sinus infection, weight loss, menstrual pain, cancer, nerve pain, itchy skin, and people inhale pepper oil to prevent falls, to help quit smoking.	Antioxidant Antimicrobial Anti-inflammatory Anti-thyroid Anti-tumor Anti-asthmatics Anti-diarrheal Anti-depressants [13,15]
19	*Mangifera indica*	Anacardiaceae	Mango	Alkaloids, flavonoids, saponins, tannins, phenols, ascorbic acid, carotenoids, glycosides and phytosterols.	The leaves are used in the burns and scalds; chewed to strengthen the gums, used for skin ailments, asthma and cough, bark is used for the treatment of fever cholera, rheumatism, to treat ulcerated tongue.	Analgesic Antimicrobial Anti-convulsant Anti-inflammatory Anti-cancer Gastro-protective Hepato-protective [13,15]
20	*Malus domestica*	Rosaceae	Apple	Phenolics, flavonoids and carotenoid, saponin, glycosides and steroid, carbohydrates, and proteins.	Used in kidney stones, constipation, blood formation, diarrhea, high blood pressure, cardiac problems, useful in sore eyes, inflammation, Alzheimer's, cancer, diabetes, gallstone, obesity loss.	Antioxidant Antimicrobial Anti-inflammatory Anti-diabetic Anti-depressant Anti-asthmatic Anti-cancer [13]
21	*Musa paradisiaca*	Musaceae	Banana	Alkaloids, flavonoids, tannins, phenolic compounds, carotenoids, anthocyanins, and cardiacglycosides.	It cures depression, treats emotional sickness, increase blood and cures anemia, reduces risk of blood pressure, menstrual cramp, helps to reduce morning sickness, constipation, ulcers, mosquito bites.	Anti-diabetic Anti-hypertensive Antioxidant Anti-diarrheal Antimicrobial Anti-cancer Anti-ulcer [13]

22	*Coriandrum sativum*	Apiaceae	Coriander	Flavanoids, alkaloids, tannins, saponin, terpenoids, sterol, carbohydrate, protein, and fat.	It treats indigestion, worm infections, rheumatism, convulsion, insomnia, anxiety, pain in the joints, used as a diuretic plant, in skin disease, effective in constipation, irritable bowel syndrome, diarrhea, measles, toothaches, nausea, hernia.	Antioxidant Diuretic Anti-diabetic Sedative Antimicrobial Anti-convulsant Anthelmintic Anti-mutagenic [13]
23	*Crinum asiaticum*	Amaryllidaceae	Spider Lily	Alkaloids, flavonoids, tannins, phenols, cardiac glycosides, triterpenes, steroids, saponins, hamayne, palmilycorine, lycoriside, ambelline, crinine, powelline, and ungeremine.	It is used to treat injury and inflamed joints, carbuncles and cancer, to treat wounds by poisoned arrows, bites and stings, swellings, fever, inflammation, piles, to stop bleeding and to treat gonorrhea, induces vomiting, toothache, ulcers.	Analgesic Antimicrobial Anti-inflammatory Antiviral Anti-cancer Anti-tumor Anti-mitotic membrane stabilizing [13, 15]
24	*Cicer arietinum*	Fabaceae	Chick Peas	Alkaloids, carbohydrates, proteins, amino acids, fixed oils, phytosterols, phenolic compounds and tannins, flavonoids, glycosides, saponins, and amino acids.	Used for insufficient milk or sperm, kidney stones, urine problems, menstruation, treats bronchitis, sunstroke, snake bites, diabetes, hypertension, itchy skin, tumor, increases bone health, controls blood pressure, prevent cancer, develops memory and thinking power.	Antioxidant Anti-hypertensive Anti-cancer Anti-inflammatory Antimicrobial Anti-diabetic Anti-pyretic Anti-cancer Estrogenic [13]

25	*Ipomoea aquatica*	Amaranthaceae	Water spinach	Flavonoids, amino acids, alkaloids, lipids, steroids, saponins, phenols, reducing sugars, tannins, β-carotene, glycosides, and minerals.	It helps to reduce cholesterol, treats jaundice and liver damages, anemia, useful for indigestion, constipation, diabetes, prevents heart attack, lowers blood pressure, boosts immunity and treats ulcer, menstruation pain, fever, rejuvenates skin.	Antioxidant Anti-inflammatory Antimicrobial Anti-diabetic Anti-diarrheal Antiseptic Anti-cancer [13]
26	*Citrus aurantiifolia*	Rutaceae	Lime	Alkaloid, glycoside, saponin, tannin, flavonoids, steroids, terpenoids, limonene, pinene, sabinene, protein, ascorbic acid and polyphenols.	It is used in headaches, cold, fever, insomnia, indigestion, to treat diarrhea, chest pain, snake bite, cancer, itching, dandruff, skin diseases, to glow skin, boiled root with alcohol is drunk to abort foetus, It prevents from microbial attack, allergy.	Antimicrobial Anti-cancer Antioxidant Immuno-modulatory Anti-obesity, Anti-fertility Anthelmintic Anti-pyretic Hepato-protective Cardio-protective [24]
27	*Citrus sinensis*	Rutaceae	Orange	Phenolics, flavonoids, carbohydrates, alkaloids, tannins, fixed oils and lipids, sugars, proteins, terpenoids, steroids, and amino acids, ascorbic acid and carotenoids.	The fruit is appetizer and blood purifier, used to treats bilious diarrhea, acne, skin disease, itching, obesity, enlarged spleen, constipation, coughs, dyspepsia, prevents digestive tract ailments, nerve disorder, blood pressure, it relieves headache and cures rheumatism.	Antimicrobial Anti-parasitic Anti-proliferative Insecticidal Relaxant, Sedative Anxiolytic Protective of UV Anti-osteoporotic Anti-obesity Hypo- cholesterolemic Antioxidant [24]

28	*Aegle marmelos*	Rutaceae	Stone apple	Phenols, flavonoids, alkaloids, cardiac glycosides, saponins, terpenoids, steroids, carbohydrate, tannins, and proteins.	Fruits and leaves are used for wound healing, curing digestive disorders, ulcers, headache, hypertension, diabetes, promotes digestion, fight against cholera, diarrhea, to cure constipation, scurvy, skin disorders, liver, heart, kidney problems.	Antimicrobial Anti-cancer Anti-inflammatory Laxative, Hepato-protective Insecticidal Anti-diabetic Anti-diarrheal Anti-ulcer Antioxidant [25]
29	*Petroselinum crispum*	Apiaceae	Parsley	Flavonoids, volatile oils, proteins, minerals, carotenes, carotenoids, ascorbic acid, coumarins, tocopherol, myristicin, essentials oils and phenolic compounds, Vitamin-A, B and C.	Used to treat asthma, bladder infections, bruises, cough, cracked or chapped skin, digestive problems, swelling, insect bites, Prevents tumor, liver disorder, kidney stones, high blood pressure, diabetes, obesity, anemia, osteoarthritis.	Antioxidant Anti-diabetic Anti-platelet Antimicrobial Hypotensive Anti-pyretic Gastro-protective Cyto-protective Laxative Analgesic [26]
30	*Cymbopogon citratus*	Gramineae	Lemon Grass	Alkaloids, glucosides, phenols, saponins, flavonoids, tannins, terpenoids, resins, citral, citronellal, cymbogonol, α-terpineol, citronellic acid, α-camphorene, geranial, isoscoparin.	Used to treat digestive problems, cramping pains, coughs, fever, to reduce swelling, improve blood circulation, bladder problems and leprosy, oil is used as an insect repellent, detergent, carminative for cholera.	Analgesic Anthelmintic Antimicrobial Anti-neoplastic Anti-malarial Antioxidant Hepato-protective Hypoglycaemic Radio-protective [13,15]

31	*Aloe barbadensis*	Asphodelaceae	Aloe vera	Flavonoids, alkaloids, aloin, carbohydrate, tannin, steroid, triterpenoids, glycosides, saponins, salicylic acids, amino acids, and beta- carotene.	Treatment of pimples, acne and mouth ulcers, laxative, wash for piles, burns, edema, pain, swellings and wounds, Juice used to increase menstrual flow and for eye disease, used in case of any type of skin problem.	Angiogenic Anti-inflammatory Anti-cancer Antimicrobial Antioxidant Dermatitis Gastric mucosal Wound healing [15]
32	*Capsicum annuum*	Solanaceae	Chili	Flavonoids, carotenoids, phenolics, capsaicin, solasdine, scopoletin, capsaicinoids, and ascorbic acid.	It is used to cure toothache, also used to increase blood circulation and stimulate gastric activities, used to treat arthritis, neuralgia, lumbago and chilblains.	Antimicrobial Anti-cancer, Antioxidant Anti-protozoal Immuno-modulatory Pesticidal [15]
33	*Ananas comosus*	Bromeliaceae	Pineapple	Flavonoids, saponins, tannins, alkaloids, terpenoids, anthraquinones, carbohydrate, steroids, phenols and glycoside.	Pineapples are rich in nutrients, low in calories, fights with oxidative stress, to treat indigestion, reduce cancer, boosts immunity, suppress inflammation, to recover surgery, kill parasites, gout, bronchitis, ulcer, cystic fibrosis.	Anti-inflammatory Hypolipidemic Laxative, Diuretic Antimicrobial Anti-obesity, Anti-diarrheal Antioxidant [13]
34	*Centella asiatica*	Apiaceae	Pennywort	Flavonoids, tannins, alkaloids, carbohydrate asiaticoside, asiatic acid, brahmic acid, brahmoside, asiaticin, centellicin, terpenoids, sterols, triterpenoids and saponins.	Used to cure diarrhea, diuretic, gravel, leprosy treatment, stones, wound healing the plant is used in cooling drinks when boiled, treatment of nervous system, skin, and blood diseases, treatment for cancer, circulatory stimulant, headache, urinary discharges, peptic ulcer and sore throat.	Antimicrobial Anti-depressant Antioxidant Anti-thrombotic Anxiolytic Gastro-protective Immuno-modulatory Nerve-regenerative Wound healing [13, 15]

35	*Agaricus bisporus*	Agaricaceae	Mushrooms	Alkaloids, flavonoids, phenols, tannins, saponins, terpenoids, cardiac glycosides, proteins, carbohydrates, fibers, and ascorbic acid.	It is effective in diabetes, cancer, hardening of arteries, to cure digestive problems, ulcer, hepatitis B, colitis, high cholesterol, osteoporosis, asthma.	Anti-cancer Anti-diabetic Antimicrobial Antioxidant Anti-ulcer Anti-hepatitis Hepato-protective [27]
36	*Trigonella foenum-graecum*	Fabaceae	Fenugreek	Flavonoids, alkaloids, terpenoids, steroids, saponins, anthocyanins, tannins, volatile oils, phenol, carbohydrates, fat, amino acids and quinones.	It is used to lower blood sugar, reduce menstrual cramps, sexual problems, used as antacid, treats dysentery, stomach disturbances, respiratory infections, fever, and hormonal disorders, induce labor pain, and inducelactation, hair growth.	Carminative Gastric stimulant Anti-diabetic Hypolipidemic Anti-ulcer Antimicrobial Antioxidant Anti-inflammatory Antacid [28]
37	*Chrysanthemum morifolium*	Asteraceae	Chrysanthemum	Alkaloids, phenols, flavonoids, caffeoylquinic acids, terpenoids, aardiac glycosides, steroids, tannins and saponins.	It is used to cure chest pain, diabetes, and fever, cold, swelling, cancer, to treat headache, inflamed eyes, and pain in the throat, boil syndrome, vertigo, tonic, urinary stones, and swelling feet.	Antimicrobial Antioxidant Anti-cancer Anti-inflammatory Anti-tussive Anti-ulcer Anti-diabetic Gastro-protective [29]

38	*Phyllanthus emblica*	Phyllanthaceae	Indian Gooseberry	Falvonoids, saponins, tannins, cardiac glycosides, alkaloids, anthraquinones, phlobotanins steroids, andcarbohydrates.	This plant is used for the treatment of jaundice, inflammation, diabetes, cough, asthma, bronchitis, dyspepsia, anemia, cures colic, peptic ulcer, skin diseases, cardiac disorders, dizziness, snake bite, vomiting, and gonorrhea.	Antimicrobial Laxative Anti-diabetic Anti-diarrheal Analgesic Anti-pyretic Hepato-protective Cardio-protective Anti-cancer[13]
39	*Boerhaavia diffusa*	Nyctaginaceae	Punarnava	Phenols, flavonoids, terpenoids, reducing sugar, ligans, organic acids, boeravinones, flavone, isoflavone, flavonol, xanthone, lignin, purine nucleoside, and sterols.	It is beneficial in treating obesity, dropsy, liver diseases, bacterial, fungal infections, intestinal worms,and bronchial tubes, treats asthma, ulcers, skin diseases, swelling, anemia, nervous weakness, paralysis, constipation, cough, mild laxative, and improves appetite, cure jaundice.	Laxative Cardio tonic Stomachic Anthelmintic Anti-inflammatory Antimicrobial Anti-metastatic Immuno-modulatory Anti-proliferative Anti-estrogenic Gastro-protective [30]
40	*Coccinia grandis*	Cucurbitaceae	Ivy Gourd	Alkaloids, glycosides, saponin, amyrine, lupeol, cucubbitacin, cephalandrol, cephalandrine, flavonoids, saponin and polyphenols.	It is useful treatment for diabetes, cancer, eye problems, skin eruptions, it is laxative, treats headache, rheumatism, high blood pressure, endocrine system disorder, stimulate weight loss, malaria, helps in constipation, hypertension, skin wounds, infections.	Anti-pyretic Anti-ulcer Antioxidant Hepato-protective Anti-cancer Anti-malarial Anti-diabetic Analgesic Anti-dyslipidemic [15]

41	*Nyctanthes arbor-tristis*	Oleaceae	Night-flowering Jasmine	Flavonoids, terpenoids, saponins, steroids, carbohydrates, cardiac glycosides, alkaloids, proteins and tannins.	It is used in various ailments like fever, enlargement of spleen, malaria, blood dysentery, gastritis, anemia, also used to treat infection of scalp, piles, skin disease, and stem bark cures rheumatic joint pain, eye disease, internal injury, diarrhea, other infections.	Anti-allergy Anti-inflammatory Anti-filarial Antimicrobial Antioxidant Anti-cancer Anti-diabetic Anti-malarial Anti-leishmanial [31]
42	*Euphorbia hirta*	Euphorbiaceae	Asthma Weed	Alkaloid, flavonoids, saponins, terpenoids, tannin, polyphenols, sugar, amino acids, euphorbon, and euphosterol.	It is used to cure asthma, calculus, cough, eruptions, headache, hypertension, measles, nausea, stomachache, warts and wounds, athlete's foot, dysentery, enteritis, fever, gas, itch, skin conditions.	Analgesic Antimicrobial Anti-diarrheal Anti-inflammatory Anti-platelet Anxiolytic Gastro-protective Molluscicidal [32]
43	*Moringa olifera*	Moringaceae	Drumstick	Alkaloids, flavonoids, steroids, tannins, saponins, glycosides, carotenoids, ascorbates, tocopherols, beta-sitosterol, moringine, and kaempferol.	It is used to treat ear infection, eye infection, toothache, cold, HIV, male impotency, blood sugar, it helps to treat high blood pressure, fever, typhoid, malaria, indigestion, diarrhea, boost immunity, cure skin diseases, treats snake bite, improves lactation in mother.	Oxidative DNA damage Cardio-protective Anti-proliferation Hepato-protective Hypolipidaemic Hypercholesterolemic Antioxidant Anti-inflammatory Antinociceptive Antimicrobial [33]

44	*Hygrophila spinosa*	Acanthaceae	Swamp Weeds	Alkaloids, flavonoids, tannins, saponins, steroids, terpenoids, phytosterol, minerals, polyphenols, proanthocyanins, mucilages, ascorbic acid, amino acids, and glycosides.	It is used to treat biliousness, blood disorders, gonorrhea, diarrhea and fever, urinary affections, rheumatism, hepatic obstruction, urinary calculi, inflammations, eye diseases, cough, joint pains, anemia, abdominal disorders.	Anti-inflammatory Anti-tumor Anti-pyretic Hepato-protective Diuretic Antioxidant Antimicrobial Analgesic [34]
45	*Bacopa monnieri*	Plantaginaceae	Waterhyssop	Flavonoid, tannin, phlobatannin, saponin, steroid, cardiac glycoside, polyphenol, carbohydrateand alkaloids.	It contains antioxidants, protects against cell damage, prevents Alzheimer's, Parkinson's disorders, reduces inflammation, cure diabetes, heart & kidney disease, boosts brain function, prevent anxiety, stress, lower blood pressure, Inhibit tumor cells, epilepsy.	Anti-depressant Anti-anxiety Anti-cancer Anti-inflammatory Antioxidant Anti-ulcer Analgesic Hypertensive Anti-diarrheal [13]
46	*Justicia adhatoda*	Acanthaceae	Malabar Nut	Alkaloids, anthraquinoes, flavonoids, carbohydrate, proteins, saponins, phytosterols, triterpenoids,and polyphenols.	Different parts of the plants have been used in cough, cold, asthma, bronchitis, tuberculosis, allergy, wound healing, it prevents intestinal parasites, dysentery, helps in skin disease, scabies etc. chest congestion, breathing problems, spasms.	Anti-tussive Hepato-protective Antimicrobial Anti-ulcer Anti-inflammatory Abortifacient Cardio-protective Thrombolytic [35]

47	*Bryonia alba*	Cucurbitaceae	Bryony	Alkaloids, saponins, steroids, triterpenoids, cucurbitane, triterpene, glycosides, carbohydratesand proteins.	It gives relief to constipation, upset stomach, fluid retention, arthritis, inflammation, headache, migraine, prevents cancer, lung disorder, vomiting, wounds, ulcer, edema, rheumatism, epilepsy, snakebite, gout pain.	Analgesic Anti-inflammatory Anti-pyretic Antimicrobial Anti-viral Anti-tumor Antidote Anti-arthritic [36]
48	*Cinnamomum zeylanicum*	Lauraceae	Cinnamon	Alkaloids, flavonoids, saponins, terpenoids, cinnzeylanin, cinnzeylanol cinnamic acid, phenolic acids, tannins, and essential oils.	It is useful in upset stomach, gastrointestinal problems, diarrhea, morning sickness, cold, vomiting, urinary tract infections, vaginal infections, diabetes, and nose bleeds, colic, prevents head lice, pain-killer, mouth freshener, and cures skin problems.	Antimicrobial Anti-inflammatory Anti-cancer Antioxidant Anti-diarrheal Anti-diabetic Cardio-protective Gastro-protective [37]
49	*Vitis vinifera*	Vitaceae	Grapes	Phenolic acids, flavonols, flavon-3-ols, myricetin, peonidin, flavonoids, quercetin, tannin, anthocyanin, cyanidin, ellagic acid, and proanthocyanidins.	Leaves are used in diarrhea, unripe fruit astringent, used in throat affections, laxative, stomachic, consumption, uterine tumors, and hardness of the liver, fresh fruits, eaten or processed into wine, juice.	Antioxidant Hepato-protective Anti-carcinogenic Anti-bacterial Anti-viral Anti-diabetic Cardio-protective [38]
50	*Thymus vulgaris*	Lamiaceae	Thyme	Flavonoids, phenols, terpenoids, protein, fat, essential oils, saponins, steroids and cardiac glycosides.	Thyme is effective in anxiety, arthritis, bad breath, bronchitis, colds, sore throat, colic, diarrhea, dermatitis, gingivitis, earache, hair loss, menstrual cramps, oral thrush, reduce inflammation, swelling oftonsils.	Anti-inflammatory Anti-anxiolytic Antimicrobial Anti-tussive, Antioxidant Anti-spasmodic Insecticidal activity[39]

51	*Laurus nobilis*	Lauraceae	Bay Leaves	Alkaloids, flavonoids, tannins, limonien, cineol, linalool, terpinol, essential oil, phenols, coumarins, steroids, triterpenes and saponins.	It has been used to treat indigestion, bronchitis, influenza, upper respiratory tract disorder, arthritic, used to improve appetite, prevent cancer, urinary ailments, rheumatic pain, renal disease, migraine, skin irritation, stimulate hairgrowth.	Anti-cancer Antimicrobial Antioxidant Anti-tussive Cardio-protective Gastro-protective Nematicidal Insecticidal [13]
52	*Elettaria cardamomum*	Zingiberaceae	Cardamom	Flavonoids, carbohydrates, proteins, minerals, lipids, essential oils, terpenoids and carotenoids.	It is used to treat indigestion, vomiting, congestion of lungs, to prevent stomach pain, gripping, colic, heart burn, stomach disorder, stones, arthritis, sore muscle, scanty urination, cystitis, fight against skin disorders.	Antioxidant Anti-inflammatory Antimicrobial Anti-cancer Insecticidal Gastro-protective Anti-ulcer Anti-asthmatic [13]
53	*Diospyros virginiana*	Ebenaceae	Persimmon	Alkaloids, proanthocyanidins, flavonoids, tannins, β- carotene, zeaxanthin, phenolics, carotenoids, and dietaryfiber.	It is used to treat bloody stools, cancer, dysentery, diarrhea, for making spirits and beer; fruits are used in treatment of diarrhea, cancers, in the treatment of thrust and sore throats.	Antipyretic effect Anti-inflammatory Anti-diarrheal Gastro-protective Anti-cancer Antimicrobial [40]
54	*Withania somnifera*	Solanaceae	Ashwagandha	Flavonoids, phenolics, alkaloids, steroidal lactones, tannins, terpenoids, carbohydrates, and saponins.	It is useful in curing the bronchial asthma, chronic fever, dysentery, arthritis, emetic syndrome, insect bites, gastric, cardiovascular, hepatic disorders, nervous exhaustion, insomnia, loose teeth, diabetes, male infertility, fibromyalgia, Parkinson disease.	Anti-stress Anti-arthritic Neuro-protective Analgesic, Anti-tumor Anti-ulcer, Antioxidant Antimicrobial Abortifacient [41]

55	*Tinospora cordifolia*	Menisper maceae	Gilory	Alkaloids, flavonoids, glycosides, steroids, phenolics, aliphatic compounds, polysaccharides, protein, terpenoid, lignans, and steroids.	It is used to boost immunity, to treats heart related issues, infertility, swine flu, dengue, constipation, reduces stress, anxiety, tonsils, boosts memory, rheumatoid arthritis, improves the vision, reduces sign of aging, dark spots, pimples, fin lines.	Neuro-protective Anti-ulcer, Anti-diarrheal Analgesic, Aphrodisiac Immuno-modulatory Anti-inflammatory Gastro-protective [42]
56	*Artemisia vulgaris*	Asteraceae	Artemisia	Flavonoids, coumarins, sesquiterpene, lactones, volatile oils, insulin, alkaloids, volatile oils (camphor, camphene, caryophyllene) and essential oils.	It is used as an immunity booster, itching, burns, colic, diarrhea, constipation, irregular menstrual periods, to treat headache, fatigue, sleeping disorders, depression, asthma, improves digestion, metabolism.	Antimicrobial Anthelmintic Anti-inflammatory Anti-hypertensive Hepato-protective Antiseptic Anti-spasmodic [13]
57	*Vitex negundo*	Lamiaceae	Lagundi	Flavonoids, carbohydrates, proteins, amino acids, saponins anthraquinones, tannins, triterpenes, lignin and polyphenolics.	It is used to treat oozing from ear, obesity, diabetes, muscular pain, skin disease, cold, diarrhea, swelling of gums, arthritis, joint pain, colon cancer, effective in chronic bronchitis, scrofulous sores, used in burns, and angina.	Anti-inflammatory Antispasmodic Antimicrobial Anti-pyretic Anthelminthic Rejuvenative Tranquilizer Anti-arthritic [13]
58	*Glycyrrhiza glabra*	Fabaceae	Liquorice	Flavonoids, saponin, isoflavonoids, stilbenoids, coumarins, glycosides, carbohydrates, starches, phenolics, alkaloids, proteins, pectin, lipids, tannins, and steroids.	It improves the symptoms of eczema, sore throats, bad breath, dental plaque, indigestion, ulcer, hepatitis, kidney problems, liver injury, obesity, Parkinson disease, stomach ulcer, and enlarged ovary with cysts, infections, cancer, tuberculosis, chronic fatigue.	Anti-tumor Antimicrobial Anti-inflammatory Anti-diabetic Anti-ulcer, Anti-cancer Antioxidant Hepato-protective Anti-allergic [13]

59	*Hibiscus rosa-sinensis*	Malvaceae	China Rose	Flavanoides, tannins, anthraquinones, quinines, phenols, alkaloids, terpenoids, saponins, cardiac glycosides, mucilages, anthocyanin, myristic acid, and campesterol.	The plant is used to treat headaches respiratory and digestive tracts, skin problems, mumps, to relieve from fever, astringent for excessive menstruation, used to treat gonorrhea, diarrhea.	Anti-anxiety, Anti-cancer Anti-fertility Antioxidant Hepato-protective Hypolipidaemic Anti-diarrheal Wound healing [15]
60	*Murraya koenigii*	Rutaceae	Curry Plant	Alkaloids, flavonoids, phenols, saponins, tannins, reducing sugars, terpenoids carbohydrates, and steroids.	It treats diabetes, anemia, eye related problems, improves vision, fights against infection and germs, burns excess fat, It is useful in digestion, constipation, diarrhea, dysentery, piles, nausea, bloating, It prevents cancer, toothache, improves memory, skin, hair, respiratory problems.	Antioxidant Anti-diabetic Anti-inflammatory Anti-tumor Neuro-protective Anti-cancer, Antimicrobial Anti-diarrheal Blood purifying Gastro-protective Anti-depressant [13]
61	*Punica granatum*	Punicaceae	Pomegranate	Phenolics, flavonoids gallotannins, lipid, ellagic acid, gallic acid, punicalins, punicalagins, tannins Punicafolin, punicalagin, friedelin, and betulic acids.	It is used for diarrhea, dysentery, vomiting, eye pain, gastrointestinal disturbances, used to relieve itch, used to treat diarrhea, colitis, dysentery, leucorrhoea, paralysis, to treat piles, yellowish discharge from the vagina, nose bleed.	Anthelmintic Antimicrobial, Anti-cancer Hypoglycemic Anti-diarrheal Anti-fertility, Antioxidant Anti-convulsant Gastro-protective Hepato-protective [15]

62	*Averrhoa carambol*	Oxalidaceae	Carambola	Alkaloids, phenols, flavonoids, protein, tannins, steroids, carbohydrates and glycosides.	It is used for skin disorder, fevers, high blood pressure, diabetes, coughs, rheumatism, asthma, colic, used to treat chicken pox, ringworm infection, to relieve gastritis, angina, malaria, intestinal worms, diarrhea, and hemorrhoids.	Antioxidant Anti-inflammatory Anti-tumor Antimicrobial Anti-diabetic Anti-diarrheal Hypertensive Hypoglycemic Anti-ulcer [43]
63	*Syzygium aromaticum*	Myrtaceae	Clove	Alkaloids, glycoside, steroids, carbohydrates, terpenoids, saponins, tannins and phenolic compound.	It reduces plaque on the teeth, excessive sweating of the palms, pain, blood sugar, bacterial infections, it helps in hangovers, diarrhea, gas, dyspepsia, nausea, vomiting, swelling, cholera, earache, mosquito repellent, bone stronger.	Antimicrobial Antioxidant Anti-carcinogenic Analgesic Anti-inflammatory Anti-thrombotic Anesthetic Anti-pyretic Anti-diabetic [13]
64	*Zea mays*	Poaceae	Corn	Polyphenols, flavonoids, anthocyanins, glycosides, carotenoids, maizenic acid, maysin, rutin, and polysaccharides.	It is used to cure diabetes, cystitis, gout, prevents nose bleeding, menorrhagia, ulcer, swellings, rheumatic pain, cancer, warts, bladder infections, kidney stones, heart failure, high blood pressure, high cholesterol.	Antioxidant Antimicrobial Anti-obesity Anti-diabetic Anti-proliferative Hepato-protective Renal protective Anti-inflammatory Anti-cancer [15]

65	*Nelumbo nucifera*	Nelumbo naceae	Sacred lotus	Alkaloids, flavonoids, phenols, tannins, steroids carbohydrate, protein, fatsand glycosides.	The leaves are used to treat sunstroke, dysentery, fever, dizziness and vomiting of blood. It is also used as an antidote for mushroom poisoning and for small pox;it is used to treat cholera, worm infestation, vomiting, and exhaustion.	Anti-anxiety Antimicrobial Anti-diarrheal Anti-inflammatory Hepato-protective Antioxidant Anti-proliferative Anti-pyretic [15]
66	*Ricinus communis*	Euphorbia ceae	Castor Bean	Flavonoids, glycosides, alkaloids, steroids, terpenoids, ricinoleic acid, ricinine, ferulic acid, syringic acid, cinnamic acids, and stigmasterol.	It is used for anal prolapsed, arthritis, constipation, facial palsy, strabismus, to treat deafness, abscesses, headache, skin problems, bleeding, constipation, boils, piles warts, dandruff, and hair loss.	Anti-fertility Antioxidant Antipsychotic Anti-inflammatory Hepato-protective Haemaglutination Insecticidal [15]
67	*Bryophyllum pinnatum*	Crassulac eae	Goethe plant	Alkaloids, saponins, flavonoids, carbohydrate, sterols, fatty acids, monoarylphenolics and tannins.	The paste of the leaves are externally used for the treatment of boils, insect bites, burns, to treat dysentery, bleeding piles, fresh wounds, blood mixed diarrhea, to reduce swelling,asthma, cold, ulcer, earache, kidney stones.	Antioxidant Anti-pyretic Anti-allergic Antimicrobial Sedative, Analgesic Anti-diarrheal Anti-ulcer [44]
68	*Oxalis corniculata*	Oxalidaceae	Creeping Woodsorr el	Flavonoids, alkaloids, tannins, phenols, carbohydrates, reducing sugar, proteins, sterols, cardiac glycosides and ascorbic acid.	It is used for liver and digestive problems, headache, cures digestive problems, to stop bleeding from cuts, used as good appetizer, piles, dyspepsia, swelling, helps in insomnia, an antidote for snake bite, mercury, arsenic poisoning.	Anti-diarrheal Anti-diabetic Antimicrobial Anti-inflammatory Anti-ulcer, Anti-epileptic Wound healing Anti-scorbutic [45]

69	*Trianthema portulacastrum*	Aizoaceae	Horse purslane	Phenols, flavonoids, alkaloids, cardiac glycosides, tannins, steroids, saponins, triterpenes, lipids, carbohydrates, and proteins.	This plant has analgesic, laxative, stomachic, used in cardiac diseases, bronchitis, inflammations, piles, cancer, obstruction of the liver asthma, amenorrhea, dropsy, edema, rheumatism, anemia, ulcer, night blindness.	Antioxidant Anti-inflammatory Anti-carcinogenic Hepato-protective Anti-hyperglycemic Antinociceptive Antimicrobial [46]
70	*Scoparia dulcis*	Scrophulariaceae	Sweet Broom	Flavonoids, alkaloids, tannins, triterpenes, hexacosonal, β-sitosterol, ketone-dulcitone, amellin, carbohydrates, protein, saponins, and steroids.	It is used to treat cough, diarrhea, bronchitis, jaundice, menstrual disorder, and malaria, skin infections, used to cure headache, liver disorders, burns, anemia, urinary tract disorders, ulcer, snake bite, migraine, hepatitis, and hypertension.	Antimicrobial Anti-inflammatory Anti-malarial Anti-diabetic Anti-diarrheal Antioxidant, Anti-cancer Anti-hypertensive [47]
71	*Psidium guajava*	Myrtaceae	Guava	Flavonoids, alkaloids, anthocyanins, carotenoids, essential oils, fatty acids, lectins, phenols, saponins, tannins, triterpenes and Vitamin C.	It cures diarrhea, reduce fever, gastroenteritis, diabetes, wounds, prevents cancer, skin aging, high blood pressure, colitis, vomiting, obesity, used to treat nail, and enhances hair growth, cure heart disease, and high cholesterol.	Anti-diabetic Anti-diarrheal Antimicrobial Antioxidant, Hepato-protective, Anti-cancer Anti-inflammatory Cardio-protective [13]
72	*Artocarpus heterophyllus*	Moraceae	Jackfruit	Phenolic compounds, flavonoids, stilbenoids, arylbenzofurons, carotenoids, volatile acid, sterols, vitamins, protein and tannins.	The decoction from its seed, root and bark is used to treat digestion, diarrhea, and dysentery. Root extract used as a remedy of skin disease, asthma, fever, used to cure wounds. It heals abscesses, ear problems, ulcer, gall stones, diabetes, reduce pain, builds muscle.	Anti-inflammatory Antioxidant Hepato-protective Wound healing Anti-carcinogenic Anti-ulcer, Anti-diabetic Anti-diarrheal Antimicrobial [48]

73	*Catharanthus roseus*	Apocynaceae	Periwinkle	Alkaloids, flavonoids, terpenoids, saponins, steroids, carbohydrates, anthaquinone, glycosides, carbohydrates and protein.	It is used to treat leukemia, Hodgkin's lymphoma, and increases blood flow in brain, cures hypertension, dizziness, cranial traumas, menstrual irregularities, chronic constipation, dyspepsia, malaria, dengue, skin diseases, wasp stings, toothache, and diabetes.	Anti-carcinogenic Anti-diabetic Antioxidant Antimicrobial Anthelmintic Anti-sterility Anti-diarrheal Hypertensive Wound healing [15]
74	*Tagetes erecta*	Asteraceae	Marigold	Flavonoids, cadinol, carotenoids, isorhamnetin, saponins, triterpenes, quercetin, kaempferol, quercetagetin, phenolics and syringic acid.	It detoxifies the digestive system, heals viral inflammations, treats urinary, liver, gallbladder ailments, cure sore throats, toothaches, measles, mumps, heals cuts, scrapes, treats sunburn, diaper rash, insomnia.	Antiseptic Wound healing Analgesic Antispasmodic Anti-inflammatory Antimicrobial Stomachic Anti-ulcer [13]
75	*Heliotropium indicum*	Boraginaceae	Indian Heliotrope	Flavonoids, steroids, tannins, alkaloids, saponins, glycosides, terpenoids, phenols, and carbohydrates, and phytosterols.	Heliotrope is used to heal skin infections, stomach problems, poisonous animal bites, nervous disorders, Prevents dandruff, treats eye diseases, cure wounds, inflammation, tumor, malaria, vein disease, kidney stones, gum infection, ring worm infection.	Anti-inflammatory Antioxidant Anti-cataract Anti-tumor Anti-ulcer Anti-fertility Diuretic Antimicrobial Analgesic [49]

76	*Tectona grandis*	Verbenaceae	Teak	Alkaloids, triterpenoids, steroids, lignans, fatty esters, phenolic compounds, tannin, carbohydrate, flavonoids, and physterols.	It is useful in bronchitis, dysentery, hyperacidity, diabetes, leprosy, nerve and skin disease, to treat headache, ringworm, promote hair growth.	Anti-inflammatory Antimicrobial Antioxidant Analgesic Diuretic Laxative [10]
77	*Leucas aspera*	Lamiaceae	Thumba	Alkaloids, phytosterols, flavonoids, saponins, phenols, glycosides, oleanolic acid, ursolic acid, triterpenoids and beta-sitosterol.	Used orally as stimulant, anthelmintic, laxative, and diaphoretic, to treat inflammation, dyspepsia, and jaundice, diarrhea, used orally for gastroenteritis, cholera, malaria, syphilis, leprosy, and dysentery.	Anti-inflammatory Antimicrobial Antioxidant Hepato-protective Anti-diabetic Anti-diarrheal [50]
78	*Lantana camara*	Verbenaceae	Indian Lantana	Flavonoids, phenols, saponins, alkaloids, tannin, anthocyanins, flavones, isoflavones, coumarins, lignans, catechins, carotenoids, carbohydrates, proteins, glycosides, and steroids.	Used to treat cuts, rheumatisms, catarrhal infection, tetanus, abdominal viscera, sores, measles, malaria, chicken pox, asthma, ulcer, swelling, bilious fever, used in the treatment of skin, itches.	Anti-cancer Anti-inflammatory Anti-diabetic Anthelmintic Antimicrobial Hepato-protective Antioxidant, Larvicidal [15]
79	*Oldenlandia corymbosa*	Rubiaceae	Diamond Flower	Alkaloids, sterols, terpenes, flavonoids, saponin, glycosides, cyanogenics, tannins, resins, lactones, quinines, phenolic acids, anthocyanidins, and volatile oils.	To treat skin sores, ulcers, sore throat, bronchitis, gynecologic infections, pelvic inflammatory diseases, fever, jaundice, diarrhea, heat eruption, hepatitis, pneumonia, urinary infection, colic, constipation.	Anti-diabetic Anti-malarial Anti-inflammatory Abortifacient Antimicrobial Antioxidant Hepato-protective [51]

80	*Centipeda minima*	Asteraceae	Spreading Sneezeweed	Alkaloids, flavonoids, tannins, phenolic compounds, glycosides, fats, terpenes and carbohydrates.	It is used to prevent pain in joints, used against hepatitis, diabetes mellitus, malaria, opium poisoning, and bronchitis, in night blindness, ring worm, and fever.	Anti-angiogenic Anti-proliferative Anti-arthritic, Anti-diabetic Antioxidant Anti-inflammatory [13]
81	*Canna indica*	Cannaceae	Canna	Alkaloids, steroids, carbohydrates, proteins, flavonoids, terpenoids, cardiac glycosides, β– carotene, essential oil, lignin, diterpenes, steroids and saponins.	Used as diuretic, diaphoretic, demulcent and stimulant, flowers are used to cure eye disease, to treat dropsy, tonsillitis, malaria, diarrhea and dysentery, fever, diabetics, cancer, bruises.	Antimicrobial Anti-inflammatory Analgesic Immuno-modulatory Anti-diarrheal Anti -pyretic Anti-cancer [52]
82	*Acalypha indica*	Euphorbiaceae	Acalypha	Alkaloids, catachols, flavonoids, phenolics, tannin, saponins, triterpenoids, steroids, glycosides, anthraquinone, proteins, and amino acids.	Used in curing diabetes, leprosy, jaundice and heart disease, Used to treat asthma, ulcers, bronchitis, headache, cough dysmenorrheal, and skin disease, Also used for constipation, tummy ache, gastrointestinal irritant.	Anti-inflammatory Antimicrobial Anti-cancer Anti-diabetes Anti-obesity Anti-venom Hepato-protective [53]
83	*Sida cordifolia*	Malvaceae	Country Mallow	Flavonoids, lignin, glycosides, alkaloids, saponins, phytosterols, fixed oils, reducing sugar, and fatty acids.	Used as astringent, diuretic, tonic, cystitis, hematuria, fever, leucorrhoea, and disease of nervous system, paralysis, to treat piles, throat disease, phthisis, and sciatica.	Analgesic Anti-inflammatory Antimicrobial Hepato-protective Anthelmintic Anti-diabetic [13]

84	*Sesbania sesban*	Fabaceae	Sesban	Alkaloids, anthocyanins, polyphenols, flavonoids, phytosterol, triterpenoids, Vitamins, tannins, saponins, and glycosides.	It is used to treat diabetics, inflammation, pains, diarrhea, scorpion sting, emmenagogue astringent, skin disease, leucoderma, menorrhagia, and for spleen enlargement.	Anti-inflammatory Antioxidant Anthelminthic Anti-diabetic Antimicrobial Dermatitis Anti-pyretic Antimicrobial [54]
85	*Daucus carota*	Apiaceae	Carrot	Phenolics, carotenoids, alkaloids, flavonoids, terpenoids, polyacetylenes, ascorbic acid, uccinic acid, α- ketoglutaric acid, lactic acid, and glycolic acid.	It is used as a diuretic and treats many urinary problem kidney stone, It also used in digestive disorders such as indigestion, gas formation, also used to treat skin disease, and cancer.	Anti-inflammatory Anti-oxidant Anti-cancer Antimicrobial Anti-flu Anti-anxiety Antispasmodic [13]
86	*Cocos nucifera*	Arecaceae	Coconut	Phenols, tannins, leucoanthocyanidins, flavonoids, triterpenes, steroids, alkaloids, lpids, phytates and saponins.	Used for the treatment of diarrhea, arthritis, uterine diseases, bronchitis, liver complaints, diuretic, laxative, to treat diseased skin, teeth.	Analgesic Anti-inflammatory Antimicrobial Laxative Diuretic Hepato-protective Anti-diabetic [15]
87	*Andrographi spaniculata*	Acanthaceae	Green Chiretta	Alkaloids, steroids, flavonoids, tannins, triterpenoids, quinones, protein, and sugars.	It is used to treat diabetes, high blood pressure, ulcer, leprosy, bronchitis, colic, influenza, malaria, blood purifier, cold, constipation, fever, liver disorders, loss of appetite, urinary tract and lung infections, low sperm count.	Anti-inflammatory Anti-hyperglycemic Hepato-protective Antimicrobial Anti-cancer, Anti-viral Gastro-protective Cardio-protective [8]

88	*Phoenix dactylifera*	Arecaceae	Date Palm	Carotenoids, flavonoids, polyphenols, isoflavons, lignans, alkaloids, saponins, terpenoids, tannins, cardiac glycosides, and sterols.	Used for the treatment of memory disturbances, paralysis, loss of consciousness, inflammation, nervous disorders, diuretic, sore throat, colds, bronchial asthma, to relieve fever, cystitis, gonorrhea, liver and abdominal troubles.	Anti-ulcer, Anti-cancer Anti-diarrheal Hepato-protective Antioxidant, Anti-inflammatory, Antimicrobial Anti-hyperlipidemic [55]
89	*Morinda citrifolia*	Rubiaceae	Indian Mulberry	Alkaloids, octanoic acid, terpenoids, anthraquinones, sitosterol, carotene, Vitamin-A, flavones glycosides, amino acids, caproic acid, ursolic acid, rutin and proxeronine.	It is used in diabetes, anxiety, and high blood pressure, also used to treat in colds, flu, asthma, bronchitis, piles, depression, mental disorder, improved high frequency hearing, cure heart disease, leprosy, kidney problems and urinary discharges.	Antimicrobial, Antitumor Hypertensive activity, Mental health and improved high frequency hearing, Anti-convulsant Anti-fertility [15]
90	*Saraca asoca*	Fabaceae	Ashoka	Glycoside, flavonoids, tannins, saponins, carbohydrates, phenols, steroids, lignins, catechol, leucopetargonidin and leucocyanidin.	Used in treating hemorrhagic, uterine pain, tumors, worm infestations, bacterial infections, skin problems, leucorrhoea, internal, menstrual cycle and uterine disorders, diabetes, diseases of the blood, enlargement of abdomen.	Antimicrobial Anti-implantation Anti-tumor Anti-progestational Anti-inflammatory Antioxidant, Anti-cancer [13]
91	*Ficus benghalensis*	Moraceae	Banyan	Steroids, flavonoids, tannins, phenolics, leucocyanidin, glycosides, proteins, carbohydrates, fatty acid, amino acid, terpenoids, Vitamin C, and anthraquinones.	It is used to treat diabetes, seminal weakness, leucorrhoea, nervous disorders, burning sensation, ulcers, vomiting, vaginal complains, fever, inflammations, leprosy, syphilis, dysentery, inflammation of liver, applied for reducing pimples.	Analgesic, Anti-pyretic Anti-ulcerogenic Anti-inflammatory Antimicrobial Anti-diabetic Anti-convulsant Anti-diarrheal Hepato-protective Larvicidal [56]

92	*Tridax procumbens*	Asteraceae	Coatbuttons	Flavonoids, alkaloids, hydroxycinnamates, tannins, phytosterols, lignans, carotenoids saponins, phenols and anthocyanins.	Used to treat diabetes, insect repellent, diarrhea, hemorrhages, hair loss, wounds, inflammation, cough, stomachache, epilepsy, gastrointestinaldisorders.	Anti-diabetic Antimicrobial Antiviral, Anti-oxidant Hypo-lipidaemic Anti-hypertensive [57]
93	*Solanum nigrum*	Solanaceae	Black Night Shade	Alkaloids, flavonoids, steroids, tannins, phlobatannins, phenols, solanidine, tigogenin, tomatidenol, uttronins and solanigroside.	Used in wounds, cancerous growths, piles, abdominal pain, dysentery, inflammation, asthma, ulcer, neuralgia, heavy female discharge, diarrhea, diuretic, dysentery, febrifuge.	Anti-inflammatory Anti-diabetic Antimicrobial Antinociceptive Anti-cancer Hepato-protective [15]
94	*Terminalia arjuna*	Combretaceae	Arjuna	Flavonoids, tannins, phenols, phytosterols, saponins, alkaloids, lactones, terpenoids, Carotenoids, stilbenes, lignans, tannins and glycosides.	Used for the treatment of heart diseases, hypertension, to decrease blood pressure, hemorrhages, ulcers, tumors, earaches, dysentery, sexual diseases, urinary tract infection	Antimicrobial Antioxidant Anti-carcinogenic Anti-mutagenic Gastro-protective Anti-hypertensive Anti-atherogenic [58]
95	*Mimosa pudica*	Mimosaceae	Sensitive Plant	Alkaloids, flavonoids, cardiac glycosides, polyphenols, saponins, tannins, terpenoids, quinines, and coumarin.	Used to treat blood and bile, cure piles, jaundice, leprosy, ulcer and smallpox, dysentery, inflammations, asthma, insomnia, premenstrual syndrome.	Anti-diabetic Antioxidant Anti-hepatotoxin Anti-inflammatory Wound healing Anti-fertility [59]
96	*Momordica charantia*	Cucurbitaceae	Bitter Gourd	Flavanoids, saponins, terpenoids, coumarins, emodins, alkaloids, proteins, glycosides, anthraquinones, anthocyanins, andsteroids.	Used to treat diabetes, abortifacient, gout, jaundice, abdominal pain, leprosy, laxative, piles, pneumonia, psoriasis, purgative, rheumatism, melanoma, cancer and lymphoma.	Anti-diabetic Antimicrobial Antioxidant, Anti-tumor Anti-inflammatory Hypo-lipidaemic [60]

97	*Pterocarpus marsupium*	Fabaceae	Malabar Kino	Alkaloids, glycosides, flavonoids, flavonols, poly, phenols pterostilbene, tannins, lignans, stilbenes, sterols, and terpenoids.	Used in fractures, constipation, hemorrhages, arthritis, sores, boils, stomach pain, cholera, leprosy, toothache, tumors, dysentery, fever.	Anti-diabetic Antimicrobial Antioxidant Anti-cancer Anti-diarrheal [61]
98	*Gymnema sylvestre*	Apocynaceae	Gurmar	Alkaloids, flavanoids, glycosides, tannins, triterpene, saponins gymnemic acids, phenols, anthraquinones, and phtoseterois.	It is used in the treatment of jaundice, constipation, asthma, bronchitis, conjunctivitis, renal, calculi, laxative, jaundice, piles, colic pain, eye troubles, cardiac, and respiratory diseases.	Anti-diabetic Anti-arthritic Antimicrobial Hepato-protective Anti-cancer Anti-hyperlipidemic[62]
99	*Enicostemma littorale*	Gentianaceae	Indian Gentian	Flavonoids, steroids, quinones, cardiac glycosides, saponins, quinine, tannins, phenols, and alkaloids.	Used for treating diabetes, stomachic, tonic, reduce fever, tonic for appetite loss, improves kidney function, blood pressure, and malaria.	Anti-diabetic Antimicrobial Antioxidant Anti-inflammatory Anti-tumor [63]
100	*Clerodendrumphlomidis*	Lamiaceae	Arna	Flavonoids, glycosides, terpenoids, saponins, tannins, lignin, phenols, alkaloids, glycosides, phenylethanoid, steroid, anthraquinones, and cyanogenic acid.	Used to treat inflammation, diabetes, nervous disorder, rheumatism, urinary disorders, asthma, febrifuge, coughs, venereal infections, skin diseases, elephantiasis, tropical burns, and malaria.	Anti-diabetic Antimicrobial Antioxidant Anti-inflammatory Anti-cancer Anti-diarrheal [64]

SIGNIFICANCE OF MEDICINAL PLANTS IN PHARMACOLOGY AND PHYTOCHEMISTRY

The current chapter provides research and explanations in a concise manner on a variety of ethno medicinal plants from India that have a variety of pharmacological or therapeutic qualities that can aid to lower the risk of life-threatening disorders in humans. Numerous types of phytochemicals can operate as potent defences against various illnesses or as potent immune boosters. Studying these traditional medicinal plants, aids in developing our understanding of biological processes that will benefit human welfare and healthcare in the future. The careful treatment of these species of medicinal and aromatic plants is required for these innovative objectives. It is also necessary to cultivate and preserve them methodically. The direction of the chapter reveals the pharmacology's future developments as they emerged from observational and experimental therapies for complementary and alternative medicines. Since these plants are a rich source of dietary fibre, minerals, and vitamins, as well as significant primary and secondary metabolites, they are also employed as functional food supplements to support better health. On the basis of pharmacology, phytotherapy and phytochemistry, the plant species shown enormous promise for future usage in the pharmaceutical and nutraceutical industries [1, 5, 65,67].

CONCLUSION

The current chapter focuses on certain significant Indian traditional medicinal plants and their extensive potential for phytochemicals, pharmacology, therapeutics, and nutritional qualities. These medicinal plants have been utilised as a significant medicinal, pharmacological, therapeutic, pharmaceutical, and nutritional source for many disorders, which can be inferred through this chapter. Comprehensive research studies would provide a detailed understanding of the historically used Indian medicinal herbs, demonstrating their superior value for curing various illnesses or combating other serious, life-threatening conditions.

REFERENCES

[1] Satapathy KB, Mishra PK, Jena GSJP.(2020). Micro-botany of plants used in rituals in Jajpur district of Odisha. International Journal of Botany Studies; 5(4):1-8.

[2] Al-Snafi AE. (2017). Pharmacology and Therapeutic Potential of Euphorbia hirta (Syn: Euphorbia pilulifera) - A Review. IOSR Journal of Pharmacy; 7(3):07-20.

[3] World Health Organization. (1991). “Guidelines for Assessment of the Herbal Medicines”. Programme on Traditional Medicine. WHO, Geneva, 56-91.

[4] Ghosh P, Das P, Mukherjee R, Banik S, Karmakar S, Chatterjee S. (2018). Extraction and quantification of pigments from Indian traditional medicinal plants: A comparative study between tree, shrub, and herb. International Journal of Pharmaceutical Sciences and Research; 9(7):3052-3059.

[5] Kumar R, Sharma V, Kumar S. (2020). Ethnobotanical study of herbal medicinal plants of Billawar region, Jammu and Kashmir, India. International Journal of Botany Studies; 5(2):19-23.

[6] Ghosh P, Dutta A, Biswas M, Biswas S, Hazra L, Nag SK, Sil S. (2019). Phytomorphological, chemical and pharmacological discussions about Commelina benghalensis Linn. (Commelinaceae): A Review. The Pharma Innovation Journal; 8(6):12-18.

[7] Ghosh P, Das C, Biswas S. (2020). Phytochemical Composition Analysis and Evaluation of *In-vitro* Medicinal Properties and Cytotoxicity of Five Wild Weeds: A Comparative Study. F1000Research, 9:493.

[8] Md. Hossain S, Urbi Z, Sule A, Rahman KMH. (2014). Review Article Andrographis paniculata (Burm. f.) Wall.ex Nees: A Review of Ethnobotany, Phytochemistry, and Pharmacology. The Scientific World Journal, 28.

[9] Ghosh P, Biswas S, Dutta A, Biswas M, Das S, Das C. (2019). Evaluation of phytochemical constituents and antioxidant property of leaf acetone extracts of five herbaceous medicinal weeds. Journal of Pharmaceutical Sciences and Research; 11(8):2806-2813.

[10] Ramesh B Nidavani, Mahalakshmi AM. (2014). Pharmacology of Tectona grandis Linn. Short Review. International Journal of Pharmacog and Phytochemical Research; 6(1):86-90.

[11] Sarkar S, Mondal M, Ghosh P. (2020). Quantification of total protein content from some traditionally used edible plant leaves: a comparative study. Journal of Medicinal Plant Studies; 8(4):166-170.

[12] Ghosh P, Chatterjee S, Das P. (2019). Natural habitat, phytochemistry and pharmacological properties of a medicinal weed-Cleome Rutidosperma DC. (Cleomaceae): A comprehensive review. International Journal of Pharmaceutical Sciences and Research; 10(4):1605-1612.

[13] Khare CP. (2006). Indian Medicinal Plants: An Illustrated Dictionary. Berlin/Heidelberg: Springer Verlag.

[14] Banik S, Mukherjee R, Ghosh P. (2018). Estimation of plant pigments concentration from Tulsi (Ocimum sanctum Linn.): A six months study. Journal of Pharmacognosy and Phytochemistry; 7(4):2681- 2684.

[15] Ling KH, Kian CT, Hoon TC. (2009). A Guide to Medicinal Plants: An Illustrated, Scientific and Medicinal Approach. World Scientific Publishing Co. Pvt. Ltd.

[16] Paul R, Datta KA. (2011). An updated overview on Peppermint (Mentha Piperita L.). International Research Journal of Pharmacy; 2(8):1-10.

[17] Mehta D, Belemkar S. (2014). Pharmacological Activity of Spinacia oleracea Linn. A Complete Overview. Asian Journal of Pharmaceutical Research and Development, 2 (1).

[18] Tyagi S, Nanher A.H, Sahay S. (2015). Kiwifruit: Health benefits and medicinal importance. Hind agricultural and training institute; 10(2):98-100.

[19] Shrivastava RR, Pateriya P. (2018). Green tea- A short review. International Journal of Indigenous Herbs and Drugs ; 3(2):12-21.

[20] Das C, Kothari S, Muhuri A, Dutta A, Ghosh P, Chatterjee S. (2019). Clove Based Herbal Tea: development, phytochemical analysis and evaluation of antimicrobial property.Journal of Pharmaceutical Sciences and Research; 11(9):3122-3129.

[21] Abdullah Khalid M, Hussain MK. (2017). Badam (Prunus amygdalus Bail.): A fruit with medicinal properties. International Journal of Herbal Medicine; 5(5):114-117.
[22] Soni P, Singh L. (2012). Marsilea quadrifola Linn. - A valuable culinary and remedial fern in Jaduguda, Jharkhand, India. Int J of Life Science and Pharma Research; 2(3):99-104.
[23] Ali W, Hamiduddin, Ahmad A, Tukh- E- Kahu. (2016). (Lactuca Sativa Linn.): pharmacological and phytochemical profile and uses in unani medicine. Journal of Pharmaceutical and Scientific Innovation; 5(1):1-4.
[24] Sidana J, Saini V, Dahiya S. (2013). A Review on Citrus- "The Boon of Nature". International Journal of Pharmaceutical Sciences Review and Research; 18(2):20-27.
[25] Upadhyay RK. (2015). Bel plant: A source of pharmaceuticals and ethno medicines. International Journal of Green Pharmacy; 9 (4): 204-222.
[26] Chauhan ES, Aishwarya J. (2018). Nutraceuticals potential of Petroselinum Crispum: A Review. Journal of Complementary Medicine and Alternative Healthcare: 7 (2).
[27] Atila F, Owaid MN. (2017). The nutritional and medical benefits of Agaricus bisporus: a review. Journal of Microbiology, Biotechnology and Food Sciences; 7 (3): 281-286.
[28] Wani SA, Kumar P. (2018). Fenugreek: A review on its nutraceutical properties and utilization in various food products. J of the Saudi Society of Agricultural Sciences; 17(2):97-106.
[29] Shahrajabian MH, Sun W, Zandi P. (2019). A review of Chrysanthemum, the eastern queen in traditional Chinese medicine with healing power in modern pharmaceutical sciences. Applied Ecology and Environmental Research; 17(6):13355-13369.
[30] Essiett UA, Okoko AI. (2013). Comparative nutritional and phytochemical screening of the leaves and stems of Acalypha fimbricata Schum. & Thorn. And Euphorbia hirta Linn. Bulletin of Environment, Pharmacology and Life Sciences; 2(4):38-44.
[31] Srivastava R, Trivedi D, Shukla G. (2018). Nyctanthes arbor- tristis: A Wonder Indian herbal drug needs healthcare attention; 5(3):4527-4530.
[32] Ghosh P, Ghosh C, Das S, Das C, Mandal S, Chatterjee S. (2019). Botanical description, phytochemical constituents and pharmacological properties of Euphorbia hirta Linn. A Review. International Journal of Health Sciences and Research; 9(3):273-286.
[33] Saini RK, Sivanesan I. (2016). Phytochemicals of Moringa oleifera: a review of their nutritional, therapeutic and industrial significance. Springer; 6:203.
[34] Kshirsagar AD, Ingale KG, Vyawahare NS, Thorve VS. (2010). Hygrophila spinosa: A comprehensive review. Pharmacognosy Reviews; 4(8):167-171.
[35] Singh KJ, Huidrom D. (2013). Ethnobotanical uses of medicinal plant, Justicia adhatoda L. by Meitei community of Manipur, India. Journal of Coastal Life Medicine; 1(4):322-325.
[36] Kujawska M, Svanberg I. (2019). From medicinal plant to noxious weed: Bryonia alba L. (Cucurbitaceae) in northern and eastern Europe. Journal of ethnobiology and Ethnomedicie; 15(22):1-12.
[37] Rao PV, Gan SH. (2014). Cinnamon: A Multifaceted Medicinal Plant. Evidence-Based Complementary and Alternative Medicine, 12.
[38] Kanagarla, Kuppast IJ. (2013). A review on benefits and uses of Vitis vinifera (Grape). Research and Reviews in Biosciences; 7(5):175-180.

[39] Reddy PV, Reddy RV, Varsha PV, Satyam S. (2014). Review on Thymus vulgaris Traditional Uses and Pharmacological Properties. Medicinal and Aromatic Plants, 3:3.

[40] Briand CH. (2005). The common persimmon (Diospyos virginiana L.): The history of a underutilized fruit tree (16th- 19th centuries). Hunt Institute for Botanical Documentation; 12(1):71-88.

[41] Verma SK, Kumar A. (2011). Therapeutic uses of Withania Somnifera (Ashwagandha) with a note on Withanolide and its Pharmacological actions. Asian Journal of Pharmaceutical and Clinical Research; 4(1):1-4.

[42] Bharathi C, Reddy AH, Nageswari G, Sri Lakshmi B, Soumya M, Vanisri DS. (2018). A Review on Medicinal Properties of Tinospora cordifolia. International Journal of Scientific Research and Review; 7(12):585- 598.

[43] Saghir SA, Sadikun A, Khaw AW. (2013). Star fruit (Averrhoa carambola L): From traditional uses to pharmacological activities. Boletin Latinoamericano del Caribe de Plantas Medicinales y Aromaticas; 12(3):209- 219.

[44] Nagaratna A, Hegde PL. (2015). A comprehensive review on Parnabeeja [Bryophyllum pinnatum (lam.) Oken]. Journal of Medicinal Plants Studies; 3(5):166- 171.

[45] Sarkar T, Ghosh P, Poddar S, Choudhury S, Sarkar A, Chatterjee S. (2020). Oxalis corniculata Linn. (Oxalidaceae): A brief review. J of Pharmacognosy and Phytochemistry; 9(4):651-655.

[46] Poddar S, Ghosh P, Sarkar T, Choudhury S, Sarkar A, Chatterjee S. (2020). Phytochemical, Ethnobotanical and Phytopharmacological Discussions about Trianthema portulacastrum Linn.: A Brief Review. Journal of Pharmaceutical Sciences and Research;12(7):899-903.

[47] Sarkar A, Ghosh P, Poddar S, Sarkar T, Choudhury S, Chatterjee S. (2020). Phytochemical, Botanical and Ethnopharmacological Study of Scoparia dulcis Linn. (Scrophulariaceae): A Mini Review. The Pharma Innovation Journal; 9(7):30-35.

[48] Baliga MS, Shivashankara AR, Haniadka R, Dsouza J, Bhat HP. (2011). Phytochemistry, nutritional and pharmacological properties of Artocarpus heterophyllus Lam (Jackfruit): A review. Food Research International; 44(9):3123.

[49] Ghosh P, Das P, Das C, Mahapatra S, Chatterjee S. (2018). Morphological characteristics and phyto- pharmacological detailing of Hatishur (Heliotropium indicum Linn.):A concise review. Journal of Pharmacognosy and Phytochemistry; 7(5):1900- 1907.

[50] Prajapati MS, Patel JB, Modi K, Shah MB. (2010). Leucas aspera: A review, Pharmacognosy Reviews; 4(7): 85-87.

[51] Das S, Mondal N, Mondal S, Ghosh P. (2019). Botanical features, phytochemical and pharmacological overviews of Oldenlandia corymbosa Linn. A brief review. The Pharma Innovation Journal; 8(2):464-468.

[52] Al-Snafi AE. (2015). Bioactive Components and Pharmacological Effects of Canna indica - An Overview. International Journal of Pharmacology and Toxicology; 5(2):71-75.

[53] Nag A, Anoop M, Sharma K, Verma K. (2018). Acalypha Indica L. an Important Medicinal Plant with Antimicrobial agents: a Review. International Journal of Research and Analytical Reviews, 5(4).

[54] Goswami S, Mishra KN, Singh RP, Prashant Singh, Singh P. (2016). Sesbania sesban, A Plant with Diverse Therapeutic Benefits: An Overview. Journal of Pharmaceutical Research & Education; 1(1):111- 121.

[55] Vyawahare N, Pujari R, Khsirsagar A, Ingawale D, Patil M, Kagathara V. (2009). Phoenix dactylifera: An update of its indigenous uses phytochemistry and pharmacology. International Journal of Pharmacology, 7(1).

[56] Patel R, Gautam P. (2014). Medicinal Potency of Ficus bengalensis: A Review. International Journal of Medicinal Chemistry and Analysis; 4(1):53-58.

[57] Ghosh P, Biswas S, Biswas M, Dutta A, Sil S, Chatterjee S. (2019). Morphological, Ethnobiological and Phytopharmacological Attributes of Tridax procumbens Linn. (Asteraceae): A Review. International J of Scientific Research in Biological Sciences; 6(2):182-191.

[58] Alam A, Anchan K, Iwuala E. (2019). Contemporary medicinal uses of ethnomedicinally important plant: Arjuna [Terminalia arjuna (Roxb.) Wight and Arn.]. Annals of Phytomedicine: An International Journal; 8(1):63-69.

[59] Joseph B, George J, Mohan J. (2013). Pharmacology and traditional uses of Mimosa pudica. International Journal of Pharmaceutical Sciences and Drug Research; 5(2):41-44.

[60] Bortolotti M, Mercatelli D, PolitoL. (2019). Momordica charantia, a Nutraceutical Approach for Inflammatory Related Diseases. Frontiers in Pharmacology.

[61] Devgun M, Nanda A, Ansari SH. (2009). Pterocarpus marsupium Roxb. - A comprehensive review. Pharmacognosy Reviews; 3(6):359-363.

[62] Tiwari P, Mishra BN, Sangwan NS. (2014). Phytochemical and pharmacological properties of Gymnema sylvestre: An Important Medicinal Plant. BioMed Research International, 8.

[63] Saranya R, Thirumalai T, Hemalatha M, Balaji R, David E. (2013). Pharmacognosy of Enicostemma littorale: A review. Asian Pacific Journal of Tropical Biomedicine; 3(1):79-84.

[64] Wang JH, Luan F, He XD, Wang Y, Li MX. (2018). Traditional uses and pharmacological properties of Clerodendrum phytochemicals. Journal of Traditional and Complementary Medicine; 8(1):24-38.

[65] Dutta A, Biswas S, Biswas M, Ghosh P, Ghosh C, Das S. (2019). Phytochemical screening, anti-oxidant and anti- microbial activity of leaf, stem and flower of Rangoon creeper: A comparative study. Journal of Medicinal Plants Studies; 7(2):123-130.

[66] Das C, Dutta A, Muhuri A, Kothari S, Ghosh P. (2020). Biochemical analysis and evaluation of antimicrobial properties of Theaflavin and Flavonoids-rich Extract (TFE) and its nanoconjugates: A comparative study. International Journal of Pharmaceutical Sciences and Research; 11(8):3690-3701.

[67] Singh R. (2015). Medicinal plants: A review. Journal of Plant Sciences; 3(1-1):50-55.