

BENTHAM BRIEFS IN BIOMEDICINE AND PHARMACOTHERAPY

ANTHRAQUINONES: BIOACTIVE MULTIFACETED THERAPEUTIC AGENTS



Editors:
Pardeep Kaur
Ajay Kumar
Robin
Tarunpreet Singh Thind
Kamaljit Kaur

Bentham Books

Bentham Briefs in Biomedicine and Pharmacotherapy

(Volume 3)

Anthraquinones: Bioactive Multifaceted Therapeutic Agents

Edited by

Pardeep Kaur

*Department of Botany, Khalsa College
Amritsar, Punjab, India*

Ajay Kumar

*University Centre for Research and Development (UCRD)
Chandigarh University, Mohali, Punjab, India*

Robin

Agilent Technologies India Pvt. Ltd., Chandigarh, India

Tarunpreet Singh Thind

*DST-CURIE Research & Teaching Laboratory (DCRTL)
Government College for Girls
Ludhiana, Punjab, India*

&

Kamaljit Kaur

*Department of Biotechnology, Khalsa College
Amritsar, Punjab, India*

Bentham Briefs in Biomedicine and Pharmacotherapy

(Volume 3)

Anthraquinones: Bioactive Multifaceted Therapeutic Agents

Editors: Pardeep Kaur, Ajay Kumar, Robin, Tarunpreet Singh Thind and Kamaljit Kaur

ISSN (Online): 2810-997X

ISSN (Print): 2810-9988

ISBN (Online): 978-981-5313-98-7

ISBN (Print): 978-981-5313-99-4

ISBN (Paperback): 978-981-5322-00-2

©2025, Bentham Books imprint.

Published by Bentham Science Publishers Pte. Ltd. Singapore. All Rights Reserved.

First published in 2025.

BENTHAM SCIENCE PUBLISHERS LTD.

End User License Agreement (for non-institutional, personal use)

This is an agreement between you and Bentham Science Publishers Ltd. Please read this License Agreement carefully before using the ebook/echapter/ejournal (“**Work**”). Your use of the Work constitutes your agreement to the terms and conditions set forth in this License Agreement. If you do not agree to these terms and conditions then you should not use the Work.

Bentham Science Publishers agrees to grant you a non-exclusive, non-transferable limited license to use the Work subject to and in accordance with the following terms and conditions. This License Agreement is for non-library, personal use only. For a library / institutional / multi user license in respect of the Work, please contact: permission@benthamscience.net.

Usage Rules:

1. All rights reserved: The Work is the subject of copyright and Bentham Science Publishers either owns the Work (and the copyright in it) or is licensed to distribute the Work. You shall not copy, reproduce, modify, remove, delete, augment, add to, publish, transmit, sell, resell, create derivative works from, or in any way exploit the Work or make the Work available for others to do any of the same, in any form or by any means, in whole or in part, in each case without the prior written permission of Bentham Science Publishers, unless stated otherwise in this License Agreement.
2. You may download a copy of the Work on one occasion to one personal computer (including tablet, laptop, desktop, or other such devices). You may make one back-up copy of the Work to avoid losing it.
3. The unauthorised use or distribution of copyrighted or other proprietary content is illegal and could subject you to liability for substantial money damages. You will be liable for any damage resulting from your misuse of the Work or any violation of this License Agreement, including any infringement by you of copyrights or proprietary rights.

Disclaimer:

Bentham Science Publishers does not guarantee that the information in the Work is error-free, or warrant that it will meet your requirements or that access to the Work will be uninterrupted or error-free. The Work is provided "as is" without warranty of any kind, either express or implied or statutory, including, without limitation, implied warranties of merchantability and fitness for a particular purpose. The entire risk as to the results and performance of the Work is assumed by you. No responsibility is assumed by Bentham Science Publishers, its staff, editors and/or authors for any injury and/or damage to persons or property as a matter of products liability, negligence or otherwise, or from any use or operation of any methods, products instruction, advertisements or ideas contained in the Work.

Limitation of Liability:

In no event will Bentham Science Publishers, its staff, editors and/or authors, be liable for any damages, including, without limitation, special, incidental and/or consequential damages and/or damages for lost data and/or profits arising out of (whether directly or indirectly) the use or inability to use the Work. The entire liability of Bentham Science Publishers shall be limited to the amount actually paid by you for the Work.

General:

1. Any dispute or claim arising out of or in connection with this License Agreement or the Work (including non-contractual disputes or claims) will be governed by and construed in accordance with the laws of Singapore. Each party agrees that the courts of the state of Singapore shall have exclusive jurisdiction to settle any dispute or claim arising out of or in connection with this License Agreement or the Work (including non-contractual disputes or claims).
2. Your rights under this License Agreement will automatically terminate without notice and without the

need for a court order if at any point you breach any terms of this License Agreement. In no event will any delay or failure by Bentham Science Publishers in enforcing your compliance with this License Agreement constitute a waiver of any of its rights.

3. You acknowledge that you have read this License Agreement, and agree to be bound by its terms and conditions. To the extent that any other terms and conditions presented on any website of Bentham Science Publishers conflict with, or are inconsistent with, the terms and conditions set out in this License Agreement, you acknowledge that the terms and conditions set out in this License Agreement shall prevail.

Bentham Science Publishers Pte. Ltd.

80 Robinson Road #02-00

Singapore 068898

Singapore

Email: subscriptions@benthamscience.net



CONTENTS

FOREWORD	i
PREFACE	ii
LIST OF CONTRIBUTORS	iv
CHAPTER 1 ANTHRAQUINONES: INTEGRATED PERSPECTIVES ON ANALYTICAL METHODOLOGIES AND FUNCTIONAL APPLICATIONS	1
<i>Robin, Sandhya Choudhary, Vidushi Gupta, Pardeep Kaur and Tarunpreet Singh Thind</i>	
INTRODUCTION	2
BIOSYNTHESIS OF ANTHRAQUINONES: ENZYMATIC MECHANISMS AND GENETIC INSIGHTS	3
Enzymatic Mechanisms and Genetic Insights.....	4
NATURALLY OCCURRING ANTHRAQUINONES (NOAQ)	5
Plant-Based.....	5
Bacterial Based Anthraquinones.....	6
Animal and Fungal Based Anthraquinones	7
Insect Based Anthraquinones.....	8
TOXICITY OF NATURAL ANTHRAQUINONES	9
Toxicity Mechanisms	9
CHEMICAL SYNTHESIS OF ANTHRAQUINONES	10
Basic Synthesis Methods	10
Synthetic Pathways	10
<i>Vat Dye Synthesis</i>	10
<i>Medicinal Chemistry</i>	10
Advanced Synthetic Techniques	11
BINDING INTERACTIONS	11
Anthraquinones with Bovine β -Lactoglobulin	11
<i>Binding Mechanism and Specificity</i>	11
<i>Examples of Interactions</i>	12
<i>Relevance to Drug Delivery and Nutraceuticals</i>	12
RECENT ADVANCES IN THE EXTRACTION OF ANTHRAQUINONES	12
Ultrasound-Assisted Extraction (UAE Method)	12
Super Critical Fluid Extraction (SCFE)	13
Ionic Liquid/Salt Based Aqueous Two-Phase Extraction System (ATPS)	15
Deep Eutectic Solvents (DES) Extraction	16
Pressurized Hot Water Extraction (PHWE)	17
ANALYTICAL METHODS FOR ANTHRAQUINONE DETECTION AND QUANTIFICATION	19
Spectroscopic Techniques	19
<i>UV-Visible Spectroscopy</i>	19
<i>Fluorescence Spectroscopy</i>	21
<i>Infrared (IR) Spectroscopy</i>	23
<i>Nuclear Magnetic Resonance (NMR) Spectroscopy</i>	25
Chromatographic Methods	28
<i>High-Performance Liquid Chromatography (HPLC)</i>	28
<i>Gas Chromatography (GC)</i>	29
Spectrometric Methods	32
<i>X-ray Diffraction (XRD)</i>	32
Mass Spectrometry (MS)	34
Capillary Electrophoresis (CE)	37
<i>Principle and Applications</i>	37
Emerging Techniques	39
<i>Nanomaterials</i>	39
<i>Molecular Imprinting Techniques</i>	42
APPLICATIONS	44
Food Color	44

Dye and Pigment Industry	45
Pharmaceutical Applications	45
Functional Materials	46
FUNCTIONAL MATERIALS	46
LIST OF ABBREVIATIONS	47
REFERENCES	47
CHAPTER 2 AN OVERVIEW OF CHEMISTRY AND BIOSYNTHESIS OF ANTHRAQUINONES	60
<i>Pooja Sharma and Amrit Kaur</i>	
INTRODUCTION	60
GENERAL STRUCTURE AND CHEMISTRY	62
Biosynthesis of Anthraquinone (AQs)	64
Polyketone Pathway	65
Shikimate (SA) Pathway	65
Traditional Use of Anthraquinones	70
BIOLOGICAL APPLICATION OF ANTHRAQUINONES	71
Anthraquinone as Anticancer Agent	71
Anthraquinone as Antifungal, Antibacterial, and Antiviral Agent	74
Anthraquinone as Anti-arthritis, Anti-inflammatory and Antidiabetic Agent	74
Anthraquinone as Antioxidant	74
CONCLUSION AND FUTURE PERSPECTIVES	76
REFERENCES	76
CHAPTER 3 ANTHRAQUINONES AS BIOACTIVE AGENTS: RECENT TRENDS AND DEVELOPMENTS IN PHYTOTHERAPY	81
<i>Sukhvinder Dhiman, Gulshan Kumar, Ajay Kumar, Sapna Devi, Sonika and Manoj Kumar</i>	
INTRODUCTION	82
ANTHRAQUINONES AS BIOACTIVE AGENT	82
Antimicrobial Potential of Anthraquinone	83
Anticancer Potential of Anthraquinone	84
Antioxidative and Anti-Inflammatory Potential of Anthraquinone	85
RECENT DEVELOPMENTS IN PHYTOTHERAPY	96
PHARMACEUTICAL APPLICATIONS OF ANTHRAQUINONES	98
TOXICITY & SAFETY REGULATIONS	102
CONCLUSION AND FUTURE PERSPECTIVE	103
REFERENCES	103
CHAPTER 4 ANTHRAQUINONE DERIVATIVES AS POTENT ANTI-CANCER AGENTS	112
<i>Vasantha Kumar, Prashasthi V. Rai, Ganavi D., Vijesh A. M. and Roopa Nayak</i>	
INTRODUCTION	113
Cancer and the Need for New Chemotherapeutic Agents	113
Naturally Occurring Anthraquinones in Anticancer Drug Discovery	114
ANTICANCER ACTIVITY OF EMODIN DERIVATIVES	116
ANTICANCER ALOE-EMODIN DERIVATIVES	129
ANTICANCER CHRYSOPHANOL, DAMNACANTHAL, ALIZARIN, QUINIZARIN DERIVATIVES	135
ANTICANCER ACTIVITY OF SYNTHETIC ANTHRAQUINONE DERIVATIVES	140
Mechanism of Action of Anthraquinone Derivatives	179
Toxicity of Anthraquinones	188
CONCLUSION AND FUTURE PROSPECTS	189
LIST OF ABBREVIATIONS	190
REFERENCES	192
CHAPTER 5 ROLE OF NANOTECHNOLOGY IN ANTHRAQUINONES-MEDIATED DISEASE MANAGEMENT	209
<i>Pratima P. Pandey and Maushmi S. Kumar</i>	
INTRODUCTION	209
Toxicity of Anthraquinon	211
ANTHRAQUINONE NANOPARTICLES (AQNPs) IN DISEASE MANAGEMENT	213
Diabetic Nephropathy	213

Cancer Management	215
Photodynamic Therapy	218
Antibacterial Agent	219
ANTHRAQUINONE-LOADED NANOPARTICLES EFFECTS ON VASCULAR ENDOTHELIAL GROWTH FACTOR	221
CONCLUSION	223
ACKNOWLEDGEMENTS	224
LIST OF ABBREVIATIONS	224
REFERENCES	226
CHAPTER 6 ANTHRAQUINONE-BASED NANOMATERIALS: EMERGING STRATEGIES IN CANCER THERAPY	231
<i>Shilpa, Manoj Kumar, Ajay Kumar, Simrandeep Kaur, Sonika, Gulshan Kumar and Sukhvinder Dhiman</i>	
INTRODUCTION	232
ANTHRAQUINONE-BASED NANOMATERIALS: CHEMISTRY AND SYNTHESIS	234
Chemistry and Synthesis of Anthraquinones	234
Chemical Properties and Structure of Anthraquinone-Based Nanomaterials.....	235
Chemical Properties.....	235
Structure of Anthraquinone-Based Nanomaterials	235
<i>Core Structure</i>	235
<i>Anthraquinone-Based Nanomaterials</i>	236
Anthraquinone-Based Nanomaterials: Modification and Incorporation into Nanomaterials	237
Synthesis of Anthraquinone-Based Nanomaterials	237
<i>Incorporation into Nanomaterials</i>	237
Anthraquinone-Based Nanomaterials: Structural Characteristics for Therapeutic Adaptation .	237
CURRENT INVESTIGATION OF CANCER THERAPY	240
Drug Delivery Systems	240
RECENT ADVANCEMENTS AND PROMISING RESULTS	249
Current Trends in Nanomedicine Employed in Cancer Therapy	250
Evolving Strategies in the Use of Nanomaterials/Nanomedicines	251
ANTICANCER MECHANISMS AND SIGNALING PATHWAYS OF ANMs	252
REGULATORY APPROVAL AND CLINICAL TRIALS	254
Mandatory Steps and Challenges	256
FUTURE PROSPECTS IN CLINICAL APPLICATION	256
CONCLUSION	256
LIST OF ABBREVIATIONS	257
REFERENCES	258
SUBJECT INDEX	495

FOREWORD

The book series ‘Bentham Briefs in Biomedicine and Pharmacotherapy’ is dedicated to a comprehensive understanding of pharmacology and its role in treating different diseases. The third volume, ‘Anthraquinones: Bioactive Multifaceted Therapeutic Agents’ explores the realms of anthraquinones. These pharmacologically active molecules exhibit a diverse range of structural variations and different applications. Few enzymes in their biosynthetic pathways can bring out huge diversity as they can work on a large number of similar substrates having minor modifications at different positions. This book explores various aspects of anthraquinones, including their chemical structures, biosynthetic pathways, therapeutic potential, and potential applications in cancer treatment and nanotechnology. Anthraquinones are already in use for chemotherapy of various cancers. However, creating nanoparticles of these molecules brings out a new dimension in more effective delivery of these molecules, aimed at better effectiveness and reduced toxicity. Each chapter meticulously unravels the layers of complexity surrounding these compounds, offering a panoramic view of their current scientific and practical relevance. These chapters also illuminate the future pathways they may traverse, especially in the realm of nanotechnology-enhanced therapies. I am confident that this handbook will inspire readers to actively explore, critically analyze, and collaborate in order to further advance the understanding and utilization of anthraquinones in various fields.

Arun Kumar Sharma

Department of Plant Molecular Biology
University of Delhi, South Campus
New Delhi – 110021
India

PREFACE

The exploration of anthraquinones, a class of naturally occurring aromatic compounds, represents a confluence of tradition and innovation, bridging millennia-old therapeutic practices with cutting-edge scientific research. In this third volume of the Bentham Briefs in Biomedicine and Pharmacotherapy series, titled "Anthraquinones: Bioactive Multifaceted Therapeutic Agents," we embark on a comprehensive examination of these compounds, renowned for their dynamic roles in the natural world and their therapeutic potential in medicine.

Anthraquinones, characterized by their distinctive aromatic structure, have been utilized since ancient times, most notably in traditional medicine and as natural dyes. Today, they are the subject of intensive scientific inquiry, particularly in the realm of pharmacology, where their diverse bioactivities including antimicrobial, anticancer, and anti-inflammatory effects offer promising avenues for new drug development. This volume aims to encapsulate the multifaceted nature of anthraquinones, from their chemical and biosynthetic properties to their therapeutic applications and emerging roles in nanotechnology-enhanced drug delivery.

The chapters presented herein are crafted by leading experts in the field, each delving into various aspects of anthraquinone research. The content ranges from detailed analyses of chemical structures and biosynthesis pathways to comprehensive reviews of the therapeutic uses and potential of anthraquinones, particularly in combating challenging diseases like cancer. Furthermore, the incorporation of nanotechnology in anthraquinone applications heralds a new era of precision medicine, where the delivery and efficacy of these compounds are significantly enhanced. We believe that this compilation not only serves as a repository of current knowledge but also as a catalyst for future research, inspiring continued exploration and innovation in the use of anthraquinones.

Pardeep Kaur

Department of Botany, Khalsa College
Amritsar, Punjab, India

Ajay Kumar

University Centre for Research and Development (UCRD)
Chandigarh University, Mohali, Punjab, India

iii

Robin

Agilent Technologies India Pvt. Ltd., Chandigarh, India

Tarunpreet Singh Thind

DST-CURIE Research & Teaching Laboratory (DCRTL)

Government College for Girls

Ludhiana, Punjab, India

&

Kamaljit Kaur

Department of Biotechnology, Khalsa College

Amritsar, Punjab, India

List of Contributors

Amrit Kaur	Department of Chemistry, Guru Nanak Dev University, Amritsar, Punjab-143005, India
Ajay Kumar	University Centre for Research and Development (UCRD), Chandigarh University, Mohali-140413, Punjab, India
Gulshan Kumar	Department of Chemistry, Banasthali University, Banasthali Newai-304022, Rajasthan, India
Ganavi D.	Department of Chemistry, Sri Dharmasthala Manjunatheshwara College (Autonomous), Ujire, Karnataka-574240, India
Maushmi S. Kumar	Somaiya Institute for Research and Consultancy, Somaiya Vidyavihar University, Vidyavihar (East), Mumbai – 400077, India
Manoj Kumar	Department of Microbiology, Guru Nanak Dev University, Amritsar-143005, Punjab, India
Pardeep Kaur	Department of Botany, Khalsa College, Amritsar, Punjab-143002, India
Pooja Sharma	Department of Chemistry, Guru Nanak Dev University, Amritsar, Punjab-143005, India
Prashasthi V. Rai	Department of PG Studies and Research in Chemistry, Sri Dharmasthala Manjunatheshwara College (Autonomous), Ujire, Karnataka-574240, India
Pratima P. Pandey	Somaiya Institute for Research and Consultancy, Somaiya Vidyavihar University, Vidyavihar (East), Mumbai – 400077, India
Robin	Agilent Technologies, India Pvt. Ltd., Chandigarh, India
Roopa Nayak	Department of Radiation Biology and Toxicology, Manipal School of Life Sciences, Manipal Academy of Higher Education, Manipal, Karnataka-576104, India
Shilpa	Department of Chemistry, Maharishi Markandeshwar Engineering College, Maharishi Markandeshwar (Deemed to be University), Mullana, Haryana-133207, India
Simrandeep Kaur	Department of Botanical and Environmental Sciences, Guru Nanak Dev University, Amritsar, Punjab-143005, India
Sandhya Choudhary	DST-CURIE Research & Teaching Laboratory (DCRTL), Government College for Girls, Ludhiana, Punjab-141001, India
Sukhvinder Dhiman	Institute of Nano Science and Technology, Mohali, Punjab-140306, India
Sapna Devi	Department of Microbiology, DAV University, Jalandhar-144012, Punjab, India
Sonika	Department of Chemistry, Maharishi Markandeshwar Engineering College, Maharishi Markandeshwar (Deemed to be University), Mullana, Haryana-133207, India

Tarunpreet Singh Thind	DST-CURIE Research & Teaching Laboratory (DCRTL), Government College for Girls, Ludhiana, Punjab-141001, India
Vidushi Gupta	DST-CURIE Research & Teaching Laboratory (DCRTL), Government College for Girls, Ludhiana, Punjab-141001, India
Vasanth Kumar	Department of PG Studies and Research in Chemistry, Sri Dharmasthala Manjunatheshwara College (Autonomous), Ujire, Karnataka-574240, India
Vijesh A. M.	PG Department of Chemistry, Payyanur College, Payyanur, Kannur University, Kerala-670327, India

CHAPTER 1**Anthraquinones: Integrated Perspectives on Analytical Methodologies and Functional Applications****Robin¹, Sandhya Choudhary², Vidushi Gupta², Pardeep Kaur³ and Tarunpreet Singh Thind^{2,*}**¹*Agilent Technologies India Pvt. Ltd., Chandigarh, India*²*DST-CURIE Research & Teaching Laboratory (DCRTL), Government College for Girls, Ludhiana, Punjab-141001, India*³*Department of Botany, Khalsa College, Amritsar, Punjab-143002, India*

Abstract: Anthraquinones are aromatic organic compounds essential in both nature and industry, known for their diverse applications. Anthraquinones with a chemical formula of $C_{14}H_8O_2$ are commonly found in plants like *Aloe vera* and rhubarb, fungi, lichens (a symbiosis of fungi and algae), bacteria like *Streptomyces* species, and certain animals like crinoids and sponges. It has various biological functions such as antimicrobial properties and anticancer activities. Anthraquinones are synthesized through natural processes like the polyketide and shikimate pathways within plants and extracted using methods such as ultrasound-assisted extraction and super critical fluid extraction for their isolation and purification. In the medical field, anthraquinones play a crucial role in the development of drugs like anthracyclines for cancer and metformin for diabetes treatment, showcasing their therapeutic potential. Industrially, anthraquinones find application as natural dyes in textiles, imparting vibrant colors, and as additives in papermaking to enhance the strength and durability of paper products, highlighting their versatility in diverse industrial sectors. The utilization of analytical techniques such as ultraviolet-visible (UV-Vis) spectroscopy is essential for determining the absorption spectra of anthraquinones, while high-performance liquid chromatography is crucial for separating and quantifying individual compounds, emphasizing their indispensable roles in accurate anthraquinone analysis. The compound's significance extends beyond its bioactivities, playing a vital role in various industrial applications, which underscores the ongoing research and interest in exploiting its properties for innovative solutions in healthcare, manufacturing, and environmental sustainability.

Keywords: Anthraquinones, Biological activities, Biosynthesis, Chemical synthesis, Gas chromatography, High-performance liquid chromatography,

* **Corresponding author Tarunpreet Singh Thind:** DST-CURIE Research & Teaching Laboratory (DCRTL), Government College for Girls, Ludhiana, Punjab-141001, India; E-mail: tarunthind@gmail.com

Pardeep Kaur, Ajay Kumar, Robin, Tarunpreet Singh Thind & Kamaljit Kaur (Eds.)

All rights reserved-© 2025 Bentham Science Publishers

Industrial applications, Mass spectrometry, Natural pigments, Polyketide pathway, Quinones, Shikimate pathway, Super critical fluid extraction, Ultrasound-assisted extraction.

INTRODUCTION

The group of quinones and their derivatives including benzoquinones and naphthoquinones, which constitute the large number of natural pigments are called anthraquinones. These are the aromatic organic compounds with the chemical formula $C_{14}H_8O_2$, where keto groups are located on the central ring (Fig. 1). The compounds belonging to this class are abundantly produced from natural sources like plant parts such as roots, rhizomes, flowers, and fruits, while others are present in lichens, fungi, and animals [1].

Anthraquinones are of tremendous use in biological properties such as inhibiting bacterial and fungal growth and in industrial applications by acting as a natural dye and are used in bleaching pulp for papermaking. These are phenolic compounds widely present as a skeleton of 9,10-anthraquinone. The name anthraquinones was given by Carl Graebe and Libermann in the year 1868. The synthesis of these phenolic compounds includes the oxidation of anthracene in the presence of oxidant chromium (VI). These compounds are studied in plants belonging to the *Rubiaceae* family, such as *Morinda*, *Rubia*, and *Gallium* species. These quinones are derived from anthracenes and possess a broad spectrum of bioactivities such as anticancer, cathartic, anti-inflammatory, and diuretic, and also play a potential role in autoimmune diabetes [1–3]. Anthraquinones show their potential applications in various industries, such as in medicine, with their uses as drugs or as an anticancer agent.

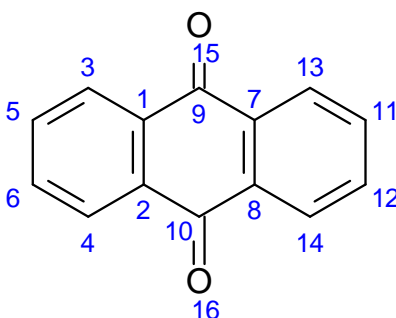


Fig. (1). Structure of anthraquinone.

BIOSYNTHESIS OF ANTHRAQUINONES: ENZYMATIC MECHANISMS AND GENETIC INSIGHTS

Anthraquinone synthesis includes 2 pathways *viz.* the polyketide pathway and the shikimate pathway.

Polyketide Pathway: This pathway is common in bacteria and fungi and is carried out in the presence of enzymes polyketide synthases that result in the formation of an intermediate during the anthraquinone synthesis (Fig. 2) [4].

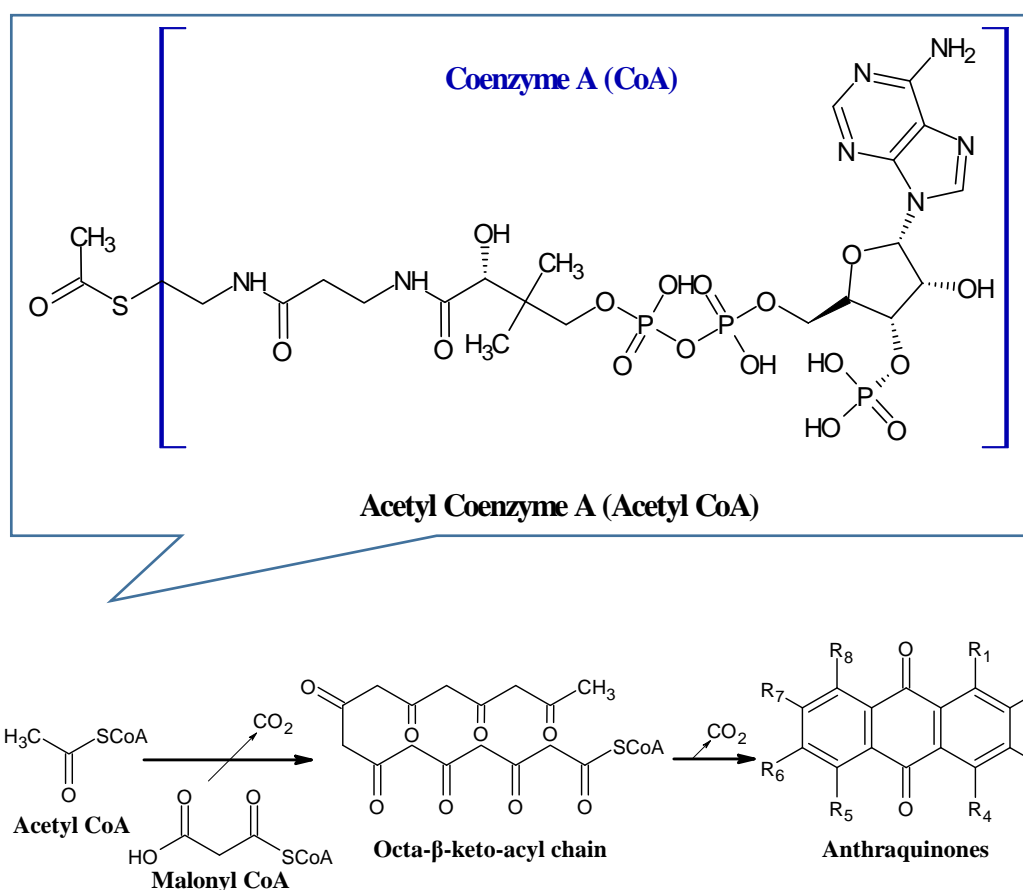


Fig. (2). The polyketide pathway.

Shikimate Pathway: α -ketoglutaric acid and shikimic acid result in the formation of o-succinoylbenzoic acid, which is further added to mevalonic acid and results in the formation of 1,2 dihydroxylated anthraquinones (Fig. 3) [1].

CHAPTER 2

An Overview of Chemistry and Biosynthesis of Anthraquinones

Pooja Sharma^{1,*} and Amrit Kaur¹

¹Department of Chemistry, Guru Nanak Dev University, Amritsar, Punjab-143005, India

Abstract: Anthraquinones are a class of secondary metabolites, have garnered significant interest due to their diverse biological activities and various industrial applications. The derivatives of anthraquinones are widely distributed in nature, being found in numerous plants, fungi, and bacteria. The biosynthetic pathways leading to anthraquinones differ among various organisms, yet common underlying mechanisms can be observed. Enzymatic reactions play a pivotal role in the functionalization and diversification of anthraquinones. Cytochrome P450 monooxygenases, glycosyltransferases, and acyltransferases are key enzymes involved in modifying the basic anthraquinone skeleton, leading to a wide array of structurally distinct derivatives. Moreover, advances in genomic and proteomic technologies have facilitated the discovery of genes and enzymes responsible for anthraquinone biosynthesis. Genetic engineering and synthetic biology approaches have enabled the manipulation of biosynthetic pathways, paving the way for the production of novel anthraquinones with enhanced bioactivity and potential applications in pharmaceuticals, agrochemicals, and the dye industry. In the present work, we will focus on the different biosynthetic pathways for the biosynthesis of anthraquinones.

Keywords: Anthracene, Aromatic fused ring, Antioxidant properties, Dye industry, 9,10-anthraquinone, Mevalonate (MVA), Methyl erythritol phosphate (MEP) quinone, Polyketone pathway, Polygonaceae, Plant pigment, Polyketide biosynthesis, Shikimate pathway, Tricarboxylic acid (TCA).

INTRODUCTION

Anthraquinone is a prominent organic compound, known for its vibrant colors and diverse activities, which has captivated the attention of chemists, scientists, and industries for centuries [1]. Its name is derived from “anthracene”, a tricyclic aromatic hydrocarbon, and “quinone”, referring to the presence of a carbonyl group

* Corresponding author Pooja Sharma: Department of Chemistry, Guru Nanak Dev University, Amritsar, Punjab-143005, India; E-mail: poojamukerian92@gmail.com

(C=O) in its chemical structure. Anthraquinone is characterized by a bicyclic core structure composed of three fused benzene rings with two ketone functional groups at adjacent carbon positions [2]. They are widely distributed in nature and play significant roles in various physiological activities. Along with their medicinal properties, natural anthraquinones are seeking attraction as an alternative to synthetic dyes which harm aquatic ecosystems [3, 4]. Anthraquinones are widely distributed in nature and can be found in various plants, fungi, and certain types of bacteria including Madder Root, Cinchona Bark, Rhubarb, and fungi [5, 6]. These are also found in various food sources of humans like cabbage, and beans, which provide around 0.04 to 36 mg of anthraquinone. The natural occurrence of anthraquinones highlights their significance in ecological and pharmacological contexts, as well as their potential as sources of bioactive compounds [7]. The chemical reactivity of anthraquinones is diverse, owing to their conjugated and electron-rich structure. They readily participate in a variety of chemical reactions (substitution, redox, cycloaddition, acid-base reactions, *etc.*), making them versatile building blocks for organic synthesis [8].

The versatility of anthraquinones extends to a wide range of applications across various fields, including chemistry (synthetic chemistry, analytical chemistry, and environmental chemistry), pharmaceuticals, dyes, biological research, and many more (Fig. 1). Anthraquinones have garnered significant attention due to their diverse pharmacological properties, including anticancer, anti-inflammatory, antibacterial, and antioxidant effects [9, 10]. Anthraquinones are commonly found in many different organisms, ranging from bacteria and fungi to plants and some animals. In plants, anthraquinones are found in a wide range of species, especially in the families; *Rubiaceae*, *Polygonaceae*, and *Rhamnaceae* [11-13]. Understanding the biosynthetic pathways of anthraquinones is crucial for both natural product synthesis and biotechnological production. Anthraquinone biosynthesis primarily occurs in plants, fungi, and certain bacteria. The biosynthetic pathways are complex and involve multiple enzymatic reactions. In plants, the biosynthesis of anthraquinones typically begins with the shikimate pathway, a central metabolic route responsible for the synthesis of aromatic compounds. This pathway usually starts with the conversion of phosphoenolpyruvate and erythrose-4-phosphate into shikimate. The second pathway is chorismic acid conversion in which chorismic acid serves as a precursor for the formation of various aromatic compounds. In the context of anthraquinone biosynthesis, it undergoes a series of reactions involving enzymes like isochorismate synthase and isochorismate-pyruvate lyase to produce isochorismic acid, which is then converted into intermediates like 1,2-dihydroxyanthraquinone, which subsequently undergoes oxidation and cyclization reactions catalyzed by various enzymes. Once the

anthraquinone skeleton is formed, various tailoring enzymes may further modify the structure [14-17]. These enzymes can introduce functional groups like hydroxyl, methyl, or glycosyl groups at specific positions on the anthraquinone ring system, yielding a wide range of anthraquinone derivatives with distinct properties. After biosynthesis, anthraquinones are often transported to specific cellular compartments, such as vacuoles, where they accumulate [18-20]. This compartmentalization helps prevent cellular damage from these often toxic compounds and also facilitates their storage for various purposes. In this context, this chapter provides an overview of the different biosynthetic pathways for the synthesis of anthraquinones.

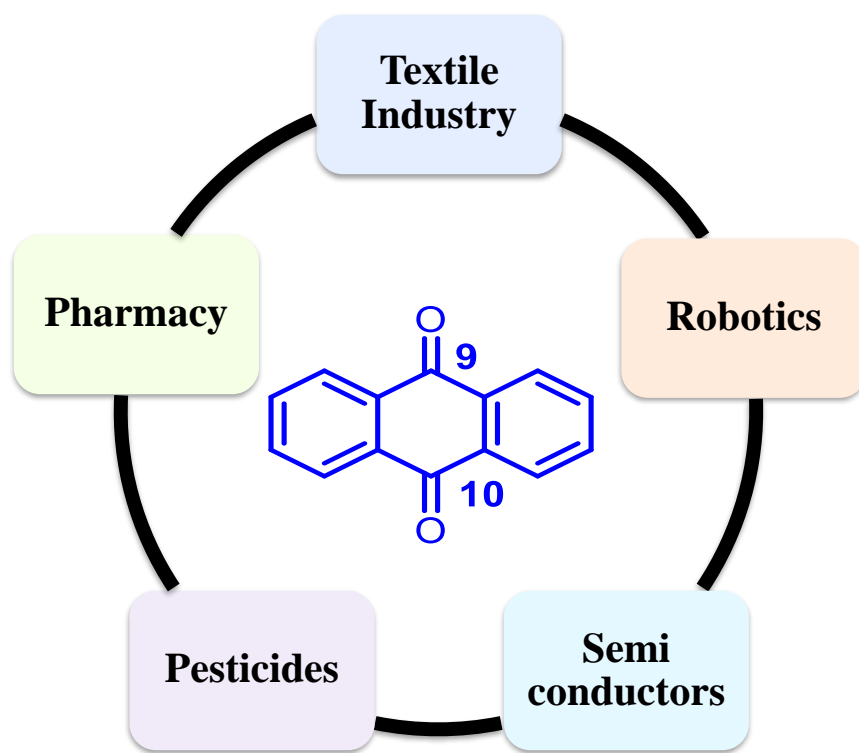


Fig. (1). Applications of anthraquinones in different fields.

GENERAL STRUCTURE AND CHEMISTRY

Anthraquinones are a class of organic compounds known as quinones and are characterized by a cyclic conjugated structure with alternating double bonds and oxygen atoms. The core structure of anthraquinone consists of three fused benzene rings, forming a tricyclic aromatic system [21]. The aromaticity of anthraquinone

CHAPTER 3

Anthraquinones as Bioactive Agents: Recent Trends and Developments in Phytotherapy

Sukhvinder Dhiman¹, Gulshan Kumar², Ajay Kumar³, Sapna Devi⁴, Sonika⁵ and Manoj Kumar^{6,*}

¹Institute of Nano Science and Technology, Mohali-140306, Punjab, India

²Department of Chemistry, Banasthali University, Banasthali Newai-304022, Rajasthan, India

³University Centre for Research and Development (UCRD), Chandigarh University, Mohali-140413, Punjab, India

⁴Department of Microbiology, DAV University, Jalandhar-144012, Punjab, India

⁵Department of Chemistry, Maharishi Markandeshwar Engineering College, Maharishi Markandeshwar (Deemed to be University), Mullana-133207, Haryana, India

⁶Department of Microbiology, Guru Nanak Dev University, Amritsar-143005, Punjab, India

Abstract: Anthraquinones are organic compounds and members of the Quinone family comprising 9, 10-anthracenedione core. Anthraquinone is a chemical scaffold that has been employed for many years in a variety of therapeutic applications such as antimicrobial, anticancer, diuretic, anti-inflammatory, and phytoestrogen activities. Anthraquinones are commonly produced as secondary metabolites in various higher plant species (senna, buckthorn, yellow dock) or they can either be synthesized using chemical routes such as the condensation of 1, 4-naphthoquinone with butadiene, naphthalene oxidation, anthracene oxidation, *etc.* Anthraquinones are used in various traditional and ethnomedical processes for the treatment of acute as well as chronic illness and are nowadays employed in modern pharmaceutical markets as a key bioactive agent. Hence, due to these properties, anthraquinone-based compounds are widely used in phytotherapy. Anthraquinones are unique in terms of their structure, chemical stability, biological properties, and industrial applications among all reported quinones, making them valuable in a wide range of drug formulations. The in-depth studies regarding the role of anthraquinones using *in vitro* and *in vivo* models need to be extensively explored for bioactive and phytotherapy applications. In addition to this, the safety and toxicity assessment need to be thoroughly investigated. The knowledge regarding its biochemical structure can pave the way to understanding its physiological and toxicological properties. The chapter dispenses compact knowledge regarding anthraquinones as potential bioactive agents and their use as a therapeutic/health product.

* **Corresponding author Manoj Kumar:** Department of Microbiology, Guru Nanak Dev University, Amritsar-143005, Punjab, India; E-mail: manojdutta27@gmail.com

Pardeep Kaur, Ajay Kumar, Robin, Tarunpreet Singh Thind & Kamaljit Kaur (Eds.)
All rights reserved-© 2025 Bentham Science Publishers

Keywords: Anthraquinones, Bioactive agents, Drug formulations, *In vivo*, *In vitro*, Medicinal plants, Toxicity studies.

INTRODUCTION

Anthraquinone, a captivating organic compound, has gained attention for its versatile applications in chemistry, pharmaceuticals, and the textile industry [1]. This aromatic compound is characterized by its unique structure, consisting of a fused aromatic ring system comprising three benzene rings and a ketone group. The term “anthraquinone” is derived from a Greek word, “anthos” meaning flower and “rhodo” meaning rose, signifying its initial discovery from the roots of madder plants, which have been employed for centuries in the production of vibrant red dyes. As time passed, the study of anthraquinone compounds expanded beyond their use in dyeing, revealing their presence in a diverse array of natural sources. Anthraquinones are frequently found in the roots, leaves, and stems of numerous plant species, including madder (*Rubia tinctorum*), rhubarb (*Rheum rhabarbarum*), and senna (*Senna alexandrina*) [2]. They are particularly abundant in plants belonging to families like *Polygonaceae*, *Rhamnaceae*, and *Juglandaceae*. More than 70 different types of anthraquinones have been identified. These compounds often serve as secondary metabolites in plants, playing essential roles in defense mechanisms against herbivores and pathogens [3]. Furthermore, anthraquinones have been identified in various fungi, notably in species belonging to the genera *Aspergillus* and *Penicillium*, where they contribute to the metabolic processes of these organisms [4]. These compounds have garnered significant interest from researchers due to their diverse biological functions, including hepatoprotective, antifungal, antibacterial, laxative, antioxidant, and anti-cancer properties. Anthraquinones have also been reported for their bioactive properties and use in phytotherapy [5-9]. In this exploration of anthraquinone, we will delve deeper into their origins and the diverse sources reported for their bioactive and phytotherapeutic properties. Also, the study related to safety and toxicity assessment needs to be explored for its pharmaceutical applications. Beyond their role as natural products, anthraquinones have found applications in synthetic chemistry, pharmaceuticals, and as colorants in various industries [10]. This makes them a versatile and captivating class of compounds with a rich history and promising prospects for the future.

ANTHRAQUINONES AS BIOACTIVE AGENT

Anthraquinones are a group of chemical compounds that are found in a wide diversity of plants and have been explored for a range of bioactive properties [11].

The various biological activities that anthraquinones exhibit make them excellent candidates for use in medicine and other applications (Table 1).

Antimicrobial Potential of Anthraquinone

Anthraquinones' antimicrobial abilities have been widely studied *in vitro* using both pure and crude forms [12]. Among the most studied anthraquinones found in nature include chrysophanol, aloe-emodin, emodin, rhein, and physcione reported for their *in vitro* antimicrobial activity. Anthraquinones, both extracted and isolated, were effective against various Gram-negative and Gram-positive bacteria including *Pseudomonas aeruginosa*, *Helicobacter pylori*, *Neisseria gonorrhoeae*, MRSA strains of *Staphylococcus aureus* and *S. epidermitis* [11]. In literature, Wang *et al.* [13], isolated a new anthraquinone, 2-(dimethoxymethyl)-1-hydroxyanthracene-9,10-dione from the fermentation of *Aspergillus versicolor* derived from sea sediment. This anthraquinone showed strong inhibitory activity against MRSA strains and moderate activity against *Vibrio campbellii* due to the inhibition of topoisomerase-IV and AmpC β -lactamase. In literature, Song *et al.* [14] isolated two anthraquinone compounds viz. 3,8-dihydroxy-1-methylanthraquinon-2-carboxylic acid and 3,6,8-trihydroxy-1-methylanthraquinone-2-carboxylic acid from an actinobacterial strain named *Kitasatospora albolonga* R62. These compounds disrupted preformed MRSA biofilms, potentially by either killing or dispersing the biofilm cells. Similarly, Shupeniuk *et al.* [15] synthesized amino derivative fragments of anthraquinone using a Ullmann coupling reaction exhibiting an inhibitory effect against a wide range of Gram-positive and Gram-negative strains of clinical isolates viz. *Staphylococcus* spp., *Streptococcus* spp., *Escherichia coli*, *Klebsiella pneumoniae*, *Providencia stuartii*, *Pseudomonas aeruginosa*, and fungal strain *Candida*. Antibacterial activity is due to the presence of benzoic acid inhibiting the active uptake of some amino and oxo acids [16]. Yirdaw and Kassa [17] reported the antibacterial activity of terpenoids and anthraquinones present in the methanol extracts from the root bark of *Ferula communis* (Apiaceae) against Gram-negative (*Salmonella typhi*, *E. coli*, *Klebsiella pneumoniae* and *Pseudomonas erogenous*), and Gram-positive bacteria (*Staphylococcus aureus*). Zhuravleva *et al.* [18] isolated different anthraquinones namely Acruciquinones A to C from marine fungus *Asteromyces cruciatus* KMM 4696, which showed significant antimicrobial effects against *Staphylococcus aureus* and *Staphylococcus aureus*-infected human HaCaT keratinocytes. The antimicrobial activity of Acruciquinones A to C is due to the inhibition of sortase A and urease activity. Recently, Adekunle *et al.* [19] isolated two anthraquinone molecules from the extracts of *Morinda lucida* viz. 2-hydroxy-1-methoxy anthraquinone and 1,2-dihydroxyanthraquinone (Alizarin), which were found to

CHAPTER 4

Anthraquinone Derivatives as Potent Anti-Cancer Agents

Vasantha Kumar¹, Prashasthi V. Rai¹, Ganavi D.², Vijesh A. M.³ and Roopa Nayak^{4,*}

¹Department of PG Studies and Research in Chemistry, Sri Dharmasthala Manjunatheshwara College (Autonomous), Ujire, Karnataka-574240, India

²Department of Chemistry, Sri Dharmasthala Manjunatheshwara College (Autonomous), Ujire, Karnataka-574240, India

³PG Department of Chemistry, Payyanur College, Payyanur, Kannur University, Kerala-670327, India

⁴Department of Radiation Biology and Toxicology, Manipal School of Life Sciences, Manipal Academy of Higher Education, Manipal, Karnataka-576104, India

Abstract: Cancer is one of the high-mortality-causing diseases in the world. It causes a serious threat to mankind with an estimated 10 million deaths every year. Identifying novel drug candidates for the treatment of various types of cancer is a prime research area in medicinal chemistry. Even though many drug molecules are used in cancer treatment, they suffer from various drawbacks, such as low selectivity, toxicity, and resistance to new tumor cells. Hence, the search for novel anti-cancer agents is a continuous process in order to develop more efficient and less toxic chemotherapeutic agents. Among them, anthraquinone, a diketo derivative of anthracene, has gained much interest in the search for novel anticancer agents. Since anthraquinone is present in various natural products, it has diverse biological properties, which makes it a prominent scaffold in medicinal chemistry. Many anthraquinone classes of anticancer agents have been developed in the last decade and remain the first treatment option for cancer. The search for novel anthraquinone derivatives by the modification of the core structure or by the introduction of newer substituents to attain higher selectivity and efficacy has gained considerable interest recently. This book chapter concisely summarizes the anticancer activities of various anthraquinone derivatives reported by researchers, either derived from natural sources or synthetically prepared.

Keywords: Anthraquinone derivatives, Anti-cancer agents, Chemotherapy, Emodin derivatives, Heterocycles, Natural products.

* **Corresponding author Roopa Nayak:** Department of Radiation Biology and Toxicology, Manipal School of Life Sciences, Manipal Academy of Higher Education, Manipal, Karnataka-576104, India; E-mail: roopa.nayak@manipal.edu

Pardeep Kaur, Ajay Kumar, Robin, Tarunpreet Singh Thind & Kamaljit Kaur (Eds.)
All rights reserved-© 2025 Bentham Science Publishers

INTRODUCTION

The group of quinones and their derivatives including benzoquinones and naphthoquinones, which constitute the large number of natural pigments are called anthraquinones. These are the aromatic organic compounds with the chemical formula $C_{14}H_8O_2$, where keto groups are located on the central ring (Fig. 1). The compounds belonging to this class are abundantly produced from natural sources like plant parts such as roots, rhizomes, flowers, and fruits, while others are present in lichens, fungi, and animals [1].

Cancer and the Need for New Chemotherapeutic Agents

Cancer is a highly assorted, multifactorial disease with a group of disorders characterized by abnormal cell growths in any part of the body, which is mainly caused by genetic and environmental factors [1]. The WHO highlighted that cancer is one of the leading causes of death in humans worldwide, and nearly 10 million mortalities were reported in 2020. That means one in every six deaths is due to cancer, which shows its brutal nature. Tobacco use, alcohol consumption, high body mass index, and low fruit and vegetable intake are the major causes of mortality from cancer [1]. Out of the 200 various types of cancers reported, lung, breast, stomach, colon and rectum, skin, and prostate cancers are the most common types found in humans. Most of the cancer types can be treated effectively only if they are detected in the early stages. It becomes more complicated in the final stages as the medication becomes ineffective and there is a possibility of recurrence after treatment.

Diagnosis of the correct types and stages of cancer is very much crucial for proper and effective treatment, because every cancer type requires a specific treatment protocol. Surgery, radiotherapy, and/or systemic therapy (chemotherapy, hormonal treatments, and targeted biological therapies) are commonly employed for curing the cancer based on the types of cancer and human beings treated. Most of the presently available cancer treatments are very expensive and cannot be afforded by a common man. Chemotherapeutic agents are the drugs used during chemotherapy, and it is one of the most common and effective cancer treatment options available. In general, cytotoxic agents destroy fast-growing cells, like cancer cells, and prevent them from multiplying. Non-selectivity of the chemotherapeutic agents and their side effects still remain a major source of concern. Neurotoxicity owing to present anti-cancer drugs can be resilient in the body even after the end of treatment, and it reduces the functional power and quality of life in cancer survivors. In their

review article, Lustberg *et al.* wrote well about the possible side effects of cancer chemotherapeutic agents [2].

Most of the anti-cancer drugs are made up of synthetic compounds, either a single derivative or a combination of drugs. Taxoids, docetaxel (Taxotere), and paclitaxel (Taxol), among other well-known anticancer medications derived from natural products, will likely lead to the discovery of many more active molecules among the 300,000 plant species that are currently being studied [3]. Different cytotoxic agents fight cancer cells *via* different mechanisms, and many are still unknown to researchers. The development of new, efficient, cheaper, and selective anti-cancer agents with fewer side effects and different mechanisms of action is crucial to the fight against cancer and to reduce mortality. Hence, this review chapter emphasizes the progress in recent developments of anticancer drugs with respect to anthraquinone derivatives with the aim of developing new derivatives as anti-cancer agents.

Naturally Occurring Anthraquinones in Anticancer Drug Discovery

Anthraquinones (Fig. 1 (1)) are naturally occurring secondary metabolites in plants [4], fungi [5], and bacteria [6]. There are 3,798 anthraquinone derivatives reported in the PubChem database. Anthraquinones have been isolated from many plants belonging to the *Rubiaceae* [7], *Fabaceae*, *Ranunculaceae*, and *Asphodelaceae* families, and anthraquinones are active ingredients used in traditional Chinese medicines [8]. Although the exact mechanism of biosynthesis of anthraquinones in plants remains unclear, polyketide and shikimate pathways are the most important and widely accepted pathways [4]. Some of the most common anthraquinones, found in plants and microbes, are emodin (Fig. 1 (2)), aloe-emodin (Fig. 1 (3)), rhein (Fig. 1 (4)), chrysophanol (Fig. 1 (5)), alizarin (Fig. 1 (6)), quinizarin (Fig. 1 (7)), damnacanthol (Fig. 1 (8)), rubiadin (Fig. 1 (9)), purpurin (Fig. 1 (10)), physcion (Fig. 1 (11)), and danthron (Fig. 1 (12)). Anthraquinones have shown a wide range of pharmacological activities, including anti-inflammatory [9], antidiabetic [10], antimicrobial [11], antiviral [12], antimalarial [13], and antiplatelet [14] activities. Natural anthraquinones have been used as photosensitizers in photodynamic therapy of cancer [15].

Emodin is one of the important naturally occurring anthraquinone molecules that exhibit diverse applications in medicinal chemistry. It is isolated from various plants belonging to the *Rhamnaceae* [16], *Polygonaceae* [17], *Fabaceae* [18], and *Asteraceae* [19] families. It is also one of the fungal metabolites and is isolated from various fungal species like *Aspergillus* [20], *Cladosporium* [21], *Chaetomium* [22],

CHAPTER 5**Role of Nanotechnology in Anthraquinones-Mediated Disease Management****Pratima P. Pandey¹ and Maushmi S. Kumar^{1,*}**

¹ *Somaiya Institute for Research and Consultancy, Somaiya Vidyavihar University, Vidyavihar (East), Mumbai – 400077, India*

Abstract: To maintain therapeutic efficacy while reducing toxicity and biocompatibility, innovative safety delivery techniques with improved nanotechnology are developed. Nanotechnology develops delivery systems that enhance the solubilizing and release quality of drugs, as well as their circulation time, which is important to enhance the therapeutic efficacy of drugs. Anthraquinones are organic substances that may be found in various plants, animals, and even some marine life. They are simple anthrones or bianthrone chemically speaking. They are used as pigments, dyes, and pharmaceuticals. Anthraquinone glycosides possess biological qualities including laxative, anti-inflammatory, anti-cancer, and antioxidants. Anthraquinones have certain drawbacks, such as their poor solubility in aqueous media, which restricts the routes of administration and lowers their bioavailability while also exhibiting a lower degree of selectivity for target tissues. It is speculated that anthraquinones and nanostructures work together. This chapter describes the application of nanotechnology in the treatment of anthraquinone-mediated diseases. The utilization of anthraquinone-loaded nanoparticles, nanocapsules, and nanocarriers in the treatment of various illnesses is highlighted.

Keywords: Anti-bacterial, Anthraquinones, Age macular diseases, Angiogenesis, Cancer, Chitosan, Diabetic nephropathy, Doxorubicin, Emodin, Liponanoparticles, Natural products, Nanocarriers, Nanoparticles, Nanotechnology, Peripheral vascular disease, Photosensitizers, Photodynamic, Rhein, Reactive oxygen species.

INTRODUCTION

For millennia, natural products have been a primary source of therapeutic agents. Nevertheless, the use of biologically active natural metabolites in pharmaceutical products and drug discovery is still a viable option. Living organisms in a variety of environments can develop various secondary metabolites, which can be useful

* **Corresponding author Maushmi S. Kumar:** Somaiya Institute for Research and Consultancy, Somaiya Vidyavihar University, Vidyavihar (East), Mumbai – 400077, India; E-mails: maushmiskumar@gmail.com; maushmi@somaiya.edu

to the organism and may have many applications for human beings Anthraquinone (AQ) is one of the main metabolites produced by various plants, marine organisms, and microorganisms, used in a broad range of applications, *e.g.*, colouring agents for foodstuffs as well as textile products which are therapeutic to different diseases [1,2]. Anthraquinones (Fig. 1) originate from the compound known as 9,10-anthracenedione. The introduction of hydroxyl, methyl, carboxyl, and methoxy functional groups onto 9,10-anthracenedione leads to the generation of several anthraquinone derivatives, exhibiting various therapeutic properties (Fig. 2) [1]. These are anthracene derivatives comprising three benzene rings and one or more hydroxyl groups that can combine with sugar molecules. Therefore, they occur in nature as anthraquinone glycosides. Anthracene compounds exist in oxidized (anthraquinone) or reduced (anthrones, anthranols) and dimer (dianthrones) forms in nature [3].

More than 75 naturally occurring AQs are identified from various natural sources which include algae, marine organisms, fungi, and medicinal plants belonging to distinct family groups. Researchers are interested in the AQ scaffold because of its broad spectrum of biological actions, which include antitumor, anti-inflammatory, anticancer, antimutagenic, anti-fungal, anti-viral, anti-malarial, anti-microbial, anti-platelet, antidiabetic, neuroprotective, antioxidant, anti-bacterial, laxative, *etc* (Table 1) [4]. Many more biological properties have been recorded with different effects [5]. In addition to its biological activities, many natural and synthetic anthraquinones are finding applications in textiles, electronic goods, biochips, food, cosmetics, medicine, and imaging photocleavage protection groups [3].

In addition, the design of new techniques has shown that an effective nanoformulation can be produced by the combination of anthraquinones and nanostructures. A potential area of research in nanotechnology involves the creation of nanocarriers that encapsulate hydrophobic and lipophilic bioactive medicines. This will improve bioavailability and broaden the spectrum of delivery strategies. Because nanocarriers are bio-compatible and bio-degradable, they offer greater opportunities for innovation and early detection of many diseases [6].

Nanotechnology is the study of nanomaterials or structures less than 100 nm with high surface density and volume ratios that could change physical chemistry, and biological parameters in chemical compositions. Nanoscience has gained worldwide interest because of its potential for applications in pharmaceuticals, diagnostics, and disease treatment [7]. Nanomaterials have a variety of qualities and characteristics, such as the required size, greater solubility, easier passage over biological barriers or an improvement in reactivity. New ambitions to tackle today's

human challenges have arisen from the use of nanotechnology. The use of nanotechnology also benefits the pharmaceutical and medical industry, resulting in new products being launched on the market [8].

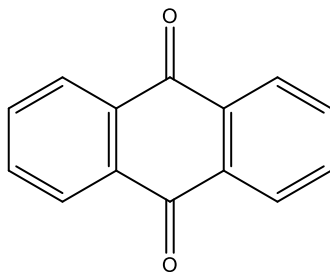


Fig. (1). Anthraquinone structure.

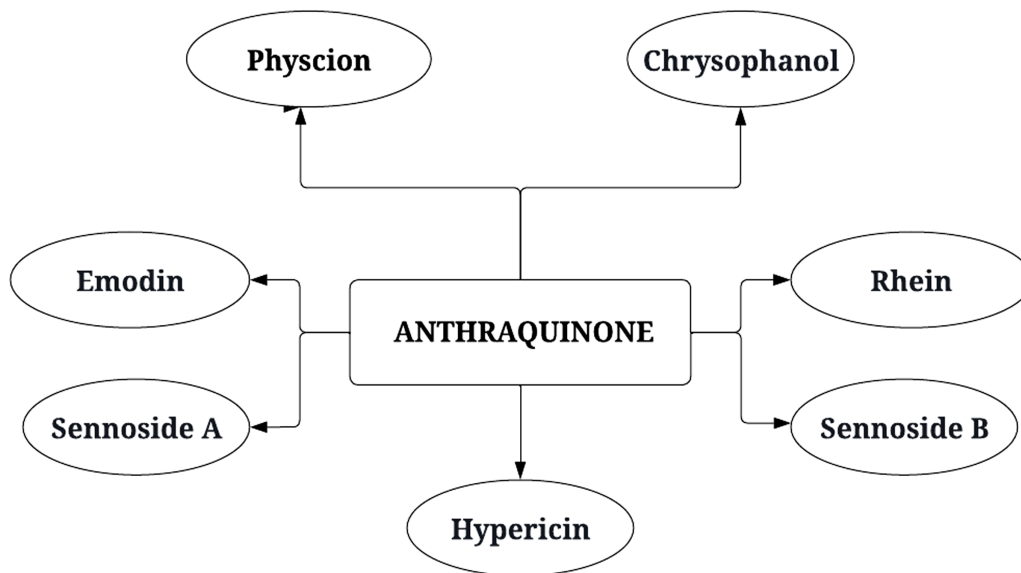


Fig. (2). Derivatives of Anthraquinone.

Toxicity of Anthraquinone

Anthraquinones are recognized for their diverse toxicological effects, which pose risks to both human health and environmental integrity. The degree of toxicity associated with these compounds can vary markedly based on the specific anthraquinone derivative and the levels of exposure involved. Certain derivatives have been classified as potential carcinogens, indicating their possible role in cancer

CHAPTER 6

Anthraquinone-Based Nanomaterials: Emerging Strategies in Cancer Therapy

Shilpa^{1,#}, Manoj Kumar^{2,#}, Ajay Kumar³, Simrandeep Kaur⁴, Sonika¹, Gulshan Kumar^{5,*} and Sukhvinder Dhiman^{6,*}

¹Department of Chemistry, Maharishi Markandeshwar Engineering College, Maharishi Markandeshwar (Deemed to be University), Mullana, Haryana-133207, India

²Department of Microbiology, Guru Nanak Dev University, Amritsar-143005, Punjab, India

³University Centre for Research and Development (UCRD), Chandigarh University, Mohali-140413, Punjab, India

⁴Department of Botanical and Environmental Sciences, Guru Nanak Dev University, Amritsar, Punjab-143005, India

⁵Department of Chemistry, Banasthali University, Banasthali Newai 304022, Rajasthan, India

⁶Institute of Nano Science and Technology, Mohali, Punjab-140306, India

Abstract: Anthraquinone-based nanomaterials (ANMs) have recently garnered considerable attention due to their potential applications in cancer therapy. Anthraquinones are characterized by their tricyclic aromatic structure, which can be modified and incorporated into nanomaterials for various therapeutic purposes in cancer treatment. There are several ways in which ANMs are currently being investigated for cancer therapy such as improved drug delivery systems, photothermal therapy, photodynamic therapy, imaging agents (anti-cancer agents), combination therapy, and biomarker detection. It is important to highlight that ongoing research in the field of nanomedicine is continuously advancing, and the exploration of ANMs for cancer therapy is a rapidly evolving area. Recent studies reported in the literature show that ANMs effectively inhibit cancer by reactive oxygen species formation, paraptosis, autophagy, apoptosis, and various cell signaling pathways. Furthermore, before these ANMs can be extensively utilized in cancer therapy, regulatory approval and clinical trials are mandatory steps in the process. The chapter outlines a comprehensive overview of ANMs, highlighting their potential use for therapeutic, cancer therapy, and various health products.

* **Corresponding authors Gulshan Kumar and Sukhvinder Dhiman:** Department of Chemistry, Banasthali University, Banasthali Newai 304022, Rajasthan, India; Institute of Nano Science and Technology, Mohali, Punjab-140306, India; E-mails: dr.gulshan.kmr@gmail.com; sukhvinderdhimank@gmail.com

#These authors contributed equally

Pardeep Kaur, Ajay Kumar, Robin, Tarunpreet Singh Thind & Kamaljit Kaur (Eds.)
All rights reserved-© 2025 Bentham Science Publishers

Keywords: Anthraquinone-based nanomaterials, Cancer therapy, Drug delivery systems, Nanomedicine, Photothermal therapy.

INTRODUCTION

Anthraquinone, derived from *Rubia* and other higher plant sources, is a tricyclic compound reported for its antioxidant properties [1-3]. It finds a wide range of applications in both industrial and medical fields due to functional activity. These compounds are derivatives of 9,10-anthracenedione, which offer several therapeutic effects in humans exhibiting antibacterial, antitrypanosomal, and antineoplastic activities [4]. Additionally, they also inhibit lipid peroxidation, intestinal motility, and human telomerase activity. Anthraquinone-based nanomaterials (ANMs) have demonstrated hepatoprotective, renal calculi elimination, immunomodulatory, anti-inflammatory, calcium channel antagonistic, antithrombotic, and DNA binding properties in both animals and humans [5]. Recent studies have shown that ANMs isolated from flowers and roots exhibit *in vitro* antitumor effects on human cancer cell lines [6-7]. These findings underscore their potential to activate antiproliferative activity and induce cytotoxic effects on these cancer cells. ANMs are recognized for their ability to induce apoptosis in various human cancer cell lines, including lung adenocarcinoma A549, myelogenous leukemia HL-60, lung squamous carcinoma CH27, cervical carcinoma HeLa cells, neuroblastoma IMR-32, bladder cancer T24, and hepatoma HepG2 cells [8]. Anthraquinone also inhibits the uptake of glucose in tumor cells, leading to alterations in membrane-associated functions that ultimately induce cell death [9].

Cancer is the second leading cause of death, with projections indicating over 21.7 million new cases and 13 million deaths attributed to this disease by 2030 [10,11]. Contemporary anticancer drugs face a lot of challenges, encompassing concerns related to their selectivity, resistance, toxicity, and limited therapeutic window. The focus has shifted to developing highly selective and potent drugs that minimize side effects. These drugs target specific factors, including DNA, topoisomerases, telomerase, MMPs, kinases, ectonucleotidase, and quinone reductase [12]. The pharmaceutical industry is placing a growing focus on targeted therapies, which is propelling the progress of novel drug formulations. The introduction of nanotechnology has brought about a revolution in drug delivery, resulting in enhanced solubility, increased bioavailability, and a reduction in toxicity [13-17]. Both natural and synthetic nanoparticles are gaining recognition and popularity because of their capability to precisely target drug delivery and improve the controlled release of medications. Within the field of cancer treatment,

nanoparticle-based delivery systems have made substantial advancements, effectively reducing toxicity and precision-based targeting only cancer cells [18-21]. Doxorubicin (DOX) is a modern Anthraquinone derivative that is being studied intensively in the field of nanotechnology to cure various tumors (Fig. 1) [22]. A heterobifunctional linker was used to create an artificial recombinant chimeric polypeptide (CP)-based near-monodisperse nanoparticle containing DOX at Cys residues. In solid tumors, CP-DOX nanoparticles are reported to accumulate preferentially.

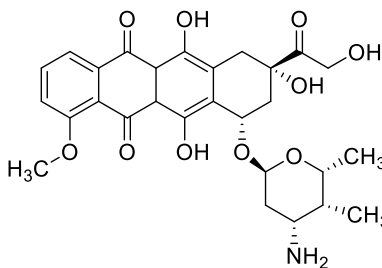


Fig. (1). Structure of Doxorubicin.

The scope of ANMs has gained significant attention in the field of cancer therapy due to their unique properties and potential applications due to their planar and aromatic ring structure making it easy to form various functionalized nanoscale structures. These nanomaterials have shown promise in several aspects of cancer therapy, and their scope includes, drug delivery systems, imaging agents, photothermal therapy (PTT), photodynamic therapy (PDT), reactive oxygen species (ROS) modulation, multimodal therapy, targeted therapies, overcoming drug resistance, nanotoxicology and biocompatibility. The potential of ANMs in cancer therapy is continuously evolving, as ongoing research strives to refine their properties and expand their applications. With increasing research efforts and the development of novel derivatives, the potential for these nanomaterials to bring about revolutionary changes in cancer therapy is on a steady path of expansion.

This chapter highlights the medicinal importance of natural anthraquinone-based nanoparticles specifically focusing on their role in anticancer activities. The creation of thoughtfully designed ANMs can pave the way for innovative approaches in chemotherapy. Various diverse nanoparticle formulations have been researched for cancer therapy and its applications in the healthcare sector. In addition to this, ongoing collaboration between scientists, engineers, healthcare professionals, and regulatory agencies will be vital in realizing these future applications.

SUBJECT INDEX

A

- Absorption 19, 20, 21, 22, 23, 217
 - bands 19, 20, 21
- Abstraction, hydrogen atom 86
- Acetyl-CoA carboxylase 68
- Acid 3, 4, 8, 16, 17, 42, 60, 61, 65, 83, 87, 97, 102, 218, 249, 252
 - benzoic 83, 87
 - boxylic 83
 - carboxylic 83
 - cassic 102
 - chitosan polylactic 218
 - choline chloride-lactic 17
 - hyaluronic 252
 - isochorismic 61
 - kermesic 8
 - lactic 16, 97
 - lactic-co-glycolic 252
 - methacrylic 42
 - mevalonic 3, 4
 - sulfonic 87
 - sulfuric 97
 - tricarboxylic 60, 65
- Action 65, 67, 74, 100, 168
 - anti-inflammatory 74
 - antiproliferative 168
 - catalytic 65
 - enzymatic 67
 - therapeutic 100
- Activity 45, 74, 81, 83, 85, 86, 87, 88, 98, 118, 120, 125, 126, 127, 145, 163, 166, 177, 179, 182, 186, 190, 212, 213, 220, 232, 254
 - anti-arthritic 98, 254
 - anti-fibrotic 212
 - anti-inflammatory 74
 - antineoplastic 232
 - anti-tumor 127
 - antiviral 45
 - inhibiting efflux pump 74
 - medicinal 190
 - metabolic 220
 - photosensitizing 213
 - phytoestrogen 81
 - protein 186
 - radical scavenging 85
 - urease 83
- Acute myeloid leukemia (AML) 99, 100
- Acytransferases 60
- Adenocarcinoma 90, 91, 163
 - pancreatic 163
- Adenosine generation 187
- Age macular diseases (AMD) 209, 222
- Agents 45, 70, 73, 113, 219, 221, 241, 242, 243, 244
 - activatable fluorescent 242
 - anthraquinone-based chemotherapy 45
 - cytotoxic 113
 - photosensitizing 241
 - photothermal 241, 243
- Anthraquinone 4, 20, 24, 38, 40, 41, 42, 67, 213, 216, 222, 234, 235, 238, 239
 - nanoparticles (AQNPs) 213, 216, 222, 234, 235, 238, 239
 - nucleus 67
 - pigments 4, 20
 - pollutants 24, 38, 41, 42
 - reduction 40
- Anti-cancer 7, 112, 114, 127, 139, 189, 215, 231
 - activity 139
 - agents 112, 114, 127, 189, 215, 231
 - treatments 7
- Antibacterial 83, 86, 87, 88, 89, 219
 - activity 83, 86, 87, 88, 89
 - agent 219
- Anticancer and antibacterial properties 92
- Antimicrobial 1, 6, 7, 45, 81, 83, 84, 88, 103, 114, 167, 212, 213, 220
 - activity 83, 84, 88, 212
 - effects 83
 - properties 1, 7

Antioxidant 35, 45, 60, 61, 74, 82, 97, 101, 103, 209, 210, 212, 218, 232, 236, 256
activity 212
effects 61
properties 45, 60, 232
Antiproliferative activity 130, 131, 143, 159, 162, 177, 178, 232
Antitumor activity 116, 127, 132, 137, 157, 161, 168, 238
Apoptosis 70, 71, 131, 132, 133, 143, 148, 154, 155, 178, 179, 212, 216, 217, 231, 232, 242, 252, 254, 257
induction 70, 143, 148, 257
tumour 71
Apoptotic pathways 217
Applications, electrochemical 32
Arthritis 74, 101, 116, 129
rheumatoid 74, 116
ATP citrate lyase inhibition 123
Autoimmune diseases 187
Autophagy 84, 168, 179, 212, 231, 254
Autophosphorylation 187

B

Bacterial Infections 223
Bioactive compounds 12, 16, 17, 21, 61
hydrophobic 17
Biodegradable polymers 220
Bladder cancer 99, 244
Bovine serum albumin (BSA) 22

C

Cancer 41, 84, 85, 91, 98, 99, 101, 112, 113, 114, 116, 140, 142, 168, 179, 182, 189, 215, 217, 222, 240, 241, 242, 244, 246, 250
anti-breast 142
biomarkers 242, 246
cell growth 101, 179, 215, 242
gastric 168
kidney 91
leukemic 140
ovarian 182, 217, 244, 250
pancreatic 217
skin 241
theranostics 41
therapy, skin 244

Cancer cells 84, 100, 168, 170, 179, 215, 216, 217, 232, 233, 241, 242, 243, 246, 248, 251, 252, 253, 254, 257
breast 84, 246
colorectal 248
gastric 168
glioblastoma 170
inhibiting 254
prostate 243
Capillary zone electrophoresis (CZE) 37
Carbonic anhydrase inhibitors (CAIs) 177
Carcinoma, thyroid 247
Cell 71, 187, 217, 252, 254
death, programmed 252
proliferation 71, 187, 217, 254
Cellular 9, 97, 179, 186
macromolecules 9
pathways 97
senescence 179
signaling 186
Cerebral ischemic stroke (CIS) 102
Chemical synthesis of anthraquinones 10
Chemotherapy 240, 257
agents 257
traditional 240
Chimeric polypeptide (CP) 233
Choriocarcinoma 116
Chorismate synthase (CS) 65, 218
Chorismic acid 61
Chromatographic 28, 34
methods 28
techniques 34
Chromatography 2, 12, 29, 30, 31, 34, 43
gas 2, 29, 30, 31, 34
Colon cancer 116, 158
Contemporary anticancer drugs 232
Cytoplasmic vacuolization 133
Cytotoxicity 84, 116, 125, 151, 153, 155, 156, 163, 166, 167, 168, 170, 216, 217, 221
activity 151
of amino acid 125

D

Damage, cellular 62, 85, 212, 252
Deep eutectic solvents (DESs) 16, 17
Degradation, photocatalytic 41
Density functional theory (DFT) 20, 27, 42

Deoxyribose nucleic acid (DNA) 21, 22, 27, 40, 100, 128, 131, 152, 179, 213, 215, 249, 250
Detection, noninvasive tumor 41
Diabetes 2, 116, 213
 autoimmune 2
Diabetic nephropathy (DN) 97, 129, 209, 213, 214, 222
Diseases 86, 103, 113, 116, 209, 210, 213, 214, 219, 223, 232, 238, 256
 anthraquinone-mediated 209
 cardiovascular 213, 223
 multifactorial 113
Disorders 71, 74, 113, 256
 autoimmune 74, 256
 neurodegenerative 256
Diversity, metabolic 5
DNA 100, 169, 179, 181, 249, 253
 fragmentation 169
 -interacting capacity 249
 replication, inhibiting 100
 strand breaks 253
 topoisomerase 181
 topology 179
DNA binding 22, 27, 120, 128, 131, 152
 property 128, 152
DNA damage 9, 157, 168, 179, 216, 252, 254
 and triggered apoptosis 168
DNA repair 250, 252
 mechanisms 250
 pathways 252
Drug(s) 1, 2, 102, 103, 113, 114, 149, 168, 209, 214, 215, 240, 241, 242, 243, 244, 250, 252, 255
 anti-inflammatory 149
 anti-tumor 241
 antileukemic 250
 chemotherapeutic 242, 252
 photosensitizing 244
Drug delivery 12, 218, 231, 232, 233, 240
 systems (DDS) 12, 231, 232, 233, 240
 vehicles 218

E

Effects 6, 11, 29, 70, 84, 85, 98, 102, 145, 165, 212, 213, 216, 242, 252, 253, 254, 257
 anti-inflammatory 85
 antimetastatic 70

 anti-migratory 84
 anti-proliferative 165, 212
 antitumor 165
 antiviral 98, 254
 apoptotic 252
 cancer-inhibitory 145
 immunomodulatory 253
 naturopathic 102
 neuroprotective 102, 213
 of anthraquinones 6, 212
 synergistic 11, 242, 257
 synergistic anticancer 216
 therapeutic anti-cancer 242
 toxic 29
Efficacy 43, 44, 98, 101, 131, 177, 217, 220, 222, 240, 243, 250, 251, 252, 255, 257
 antitumor 131, 177
 cytotoxic 217
Electrical conductivity 235
Electrocatalysis 235
Electrochemical techniques 237
Electronic devices 235
Energy storage 235, 237
Environments 7, 22, 27, 102, 187, 209, 218, 240
 acidic 218
 aromatic carbon 27
 electronic 27
 marine 7
 tumor cell 187
 tumor's immunosuppressive 240

F

FDA-approved anticancer drug 250
Flame ionization detector (FID) 31
Flow cytometry 118, 147
Fluorescence 21, 22, 23, 29, 38, 41, 214
 detection 29
 imaging 23, 41
 laser-induced 38
 spectroscopy 21, 22, 23
Food 35, 38, 40, 43, 44
 industry 43, 44
 products 35, 38, 40

G

Gas chromatography (GC) 2, 29, 30, 31, 34, 35, 36

-mass spectrometry 31, 36
Growth 2, 171, 252
fungal 2
inhibition 171, 252

H

Heat 241, 251
energy 241
therapy 251
High-performance liquid chromatography
(HPLC) 1, 2, 28, 29, 35, 44, 46
Human 22, 84, 153, 251
melanoma 84
serum albumin (HSA) 22, 153, 251
Hydrogen bond donor (HBD) 16

I

Immune 251, 253, 254
checkpoint inhibitor 251
responses 253, 254
Immunomodulatory 232
Immunotherapy 240, 242
Industrial 1, 2, 9, 10, 24, 44, 60, 64, 81
applications 1, 2, 9, 10, 24, 44, 60, 81
processes 64
Infections 7, 41, 96, 220
microbial 7, 96
skin 220
viral 41
Inflammation 74, 96, 101, 102, 253, 256
chronic 74
Information 128, 242
confirmatory 128
crucial 242
IR-active vibrations 23
Isochorismate synthase 61, 65

K

Kidney 84, 214, 215
radio-imaging technique 84
-targeting peptide (KTP) 214, 215

L

Leiomyosarcoma 246
Leukemia 100, 166, 244, 245, 247

acute lymphoblastic 166
acute myeloblastic 247
acute myelogenous 244
Leveraging techniques 46
Lipid nanoparticles 252
Lithium-ion batteries (LIBs) 32, 237
Liver injury 98
Lung 116, 246, 249, 251
cancer 116, 246, 249
carcinoma 251

M

Mass spectrometry (MS) 2, 26, 29, 34, 35, 44, 46
Medications, anti-inflammatory 98, 100
Medicinal plants, traditional 100
Metastasis 253, 254
Microspheres, biodegradable 218
Microvascular disorder 213
Mitochondrial pathways 119, 216
Molecularly imprinted polymers (MIPs) 42, 43, 44
Multiple reaction monitoring (MRM) 34, 35

N

Nano-capillary electrophoresis 38
NMR 25, 26, 27
spectroscopy 25, 26, 27
techniques 26
Non-imprinted polymers (NIPs) 44
Nuclear magnetic resonance (NMR) 25, 26, 27

O

Oxidative stress 9, 85, 86, 102, 212, 252

P

Peripheral blood mononuclear cells (PBMCs) 36
Phosphoglycerate mutase 160
Phosphorylation, tyrosine 186, 187
Photocatalysis 256
Photodynamic 98, 114, 218, 231, 233, 240, 241
therapy 98, 114, 218, 231, 233, 241

treatment 240
Phytotherapy applications 81, 103
PLGA nanoparticles 218
Polyketide 1, 2, 3, 6, 8, 46, 60, 114
 biosynthesis 60
 pathway 2, 3, 6, 8
Polyketone pathway 60, 64, 65, 66
Polymer nanoparticles 218, 223
Polymeric nanoparticles 223
Polymorphism 33
Process 11, 70, 82, 97, 243
 catalytic oxidation 11
 drug selection 243
 metabolic 70, 82
 target disease 97
Properties 6, 8, 17, 28, 37, 38, 46, 97, 100,
 141, 160, 177, 210, 213, 217, 219, 236,
 237, 238, 239, 256
 anti-inflammatory 6, 256
 anti-proliferative 100
 antibiofilm 219
 antiproliferative 217
 antipsoriatic 213
 antispasmodic 37
 antitumor 38
 biodegradable 238
 cytotoxic 8, 141
 electrochemical 46
 electron-accepting 28
 electronic 236, 237
 pharmacodynamic 97
 pharmacokinetic 160
 photochemical 38
 physicochemical 177, 219
 therapeutic 17, 210, 238, 239

Q

Quantum dots (QD) 40, 41
Quenching mechanisms 22, 23
Quinone reductase 232

R

Radiation, absorbing electromagnetic 25
Radiosensitivity 134, 157
Radiosensitization 84
Radiosensitizer, promising 134
Radiotherapy 113
Reactions 10, 11, 39, 61, 63, 65, 68, 234

acid-base 61
catalytic 68
condensation 65, 234
cyclization 61
Reactive 9, 28, 29, 30, 39, 85, 86, 95, 166,
 209, 212, 216, 233, 250, 252
 oxygen species (ROS) 9, 28, 29, 85, 86, 95,
 166, 209, 212, 216, 233, 250, 252
 standard deviations (RSDs) 30, 39
Response surface methodology (RSM) 41
Rhabdomyolysis 189

S

Scanning tunneling microscopy (STM) 33
Separation technology 16
Shikimic acid 4
Signaling 186, 253, 254
 networks 186
 pathways 253, 254
Signals, spectroscopic 39
Skin problems 218
Solid 34, 35, 233, 249
 -phase extraction (SPE) 34, 35
 tumors 233, 249
Spectrometric methods 32
Spectroscopic techniques 19
Spectroscopy, ultraviolet-visible 38
Supercritical fluid extraction (SFE) 14, 96
Surface-enhanced Raman spectroscopy
 (SERS) 39
Systems 15, 16, 17, 23, 24, 38, 40, 44, 46, 62,
 63, 64, 189, 235, 236, 241
 colonic myenteric 189
 energy storage 46, 64
 immune 241
 ionic liquid/salt aqueous two-phase 15
 liquid-based 16

T

Telomerase 179, 180, 183, 184, 185, 232
 activity 179
 inhibition 183, 184
 inhibitors 179, 183
Therapeutic approach 242
Therapies, photothermal 231, 232, 233, 240,
 241, 243
Topoisomerase(s) 86, 160, 175, 179, 180, 181,
 182, 216, 222, 232, 250, 252

- function 179
- inhibiting 160
- inhibitors 179, 181
- pathway 180
- Toxicity 212
 - colonic 212
 - kidney 212
- Transcription 21, 253
 - factor 253
 - processes 21
- Transitions 19, 20
 - electron 19
 - electronic 20
- Tumor(s) 41, 85, 91, 100, 233, 241, 247, 250, 251, 252, 257
 - angiogenesis 85, 91
 - hematologic 100
 - pancreatic 250

U

UV-Vis spectroscopy 19, 21

V

Vascular endothelial growth factor (VEGF)
158, 221, 222, 254

X

X-ray diffraction (XRD) 32, 33



Pardeep Kaur

Dr. Pardeep Kaur is an Assistant Professor in the Postgraduate Department of Botany at Khalsa College, Amritsar, Punjab, India. She holds a Ph.D. in Botany from Guru Nanak Dev University, Amritsar. Her research interests include medicinal plants, multi-herbal combinations, natural plant products, and the in-vitro/in-vivo evaluation of plant extracts and isolated compounds for various bioactivities, as well as determining their molecular mechanisms of action. She has published articles in peer-reviewed international journals with a cumulative impact factor of more than 50. She is also a reviewer for various international scientific journals.



Ajay Kumar

Dr. Ajay Kumar is an Assistant Professor at the University Centre for Research and Development (UCRD), Chandigarh University, Mohali. He holds a Ph.D. in Environmental Sciences from Guru Nanak Dev University, Amritsar. His research focuses on cancer chemoprevention using natural products. He has published extensively in high-impact journals, presented his work at various international conferences, and is a life member of the Environmental Mutagen Society of India.



Robin

Dr. Robin is an Application Scientist at Agilent Technologies India Pvt. Ltd. He earned a Ph.D. in Environmental Sciences from Guru Nanak Dev University, Amritsar. With expertise in plant extraction and activity-guided fractionation, he has over ten years of research experience and specialized knowledge in analytical instruments. He has published several research articles in internationally reputed journals. His research interests include anticancer medicinal plants, natural plant products, food chemistry, and the evaluation of isolated compounds for various bioactivities, such as antioxidant, anti-mutagenic, anti-proliferative, and anti-topoisomerase activities, as well as determining their molecular mechanisms of action.



Tarunpreet Singh Thind

Dr. Tarunpreet Singh Thind is an Assistant Professor in the Postgraduate Department of Botany at Govt. College for Girls, Ludhiana, Punjab, India. He holds a Ph.D. in Botany with a specialization in medicinal plant biotechnology and herbal drug development. With extensive experience in phytochemical analysis, antioxidative studies, and anticancer research, he has contributed significantly to natural product pharmacology. He has published research in reputed international journals. His expertise in plant-derived bioactives and integrative medicine bridges traditional knowledge with contemporary research for therapeutic innovations.



Kamaljit Kaur

Dr. Kamaljit Kaur is the Head of the Postgraduate Department of Biotechnology at Khalsa College, Amritsar. She completed her Ph.D. focusing on identifying anti-mutagenic components from medicinal plants. She has made significant contributions to understanding the effects of medicinal plants on cancer cell proliferation. Her studies on Ashwagandha's selective cytotoxic effects on cancer cells and its molecular mechanisms have shown promising results for natural cancer therapies. Her research also includes studies on drug resistance and molecular mechanisms related to cancer and aging. With extensive experience in molecular and cancer biology, she continues to contribute to innovative cancer therapies.