

QUINONES: A PRIVILEGED MOIETY FOR DRUG DISCOVERY

Editors:

Ashutosh Kumar Dash
Deepak Kumar

Bentham Books

Quinones: A Privileged Moiety for Drug Discovery

Edited by

Ashutosh Kumar Dash

*R & D, Drug Discovery Division
Macleods Pharmaceuticals, India*

&

Deepak Kumar

*Department of Pharmaceutical Chemistry, School of
Pharmaceutical Sciences, Shoolini University, Solan-173229,
Himachal Pradesh, India*

Quinones: A Privileged Moiety for Drug Discovery

Editors: Ashutosh Kumar Dash & Deepak Kumar

ISBN (Online): 979-8-89881-027-6

ISBN (Print): 979-8-89881-028-3

ISBN (Paperback): 979-8-89881-029-0

© 2025, Bentham Books imprint.

Published by Bentham Science Publishers Pte. Ltd. Singapore, in collaboration with Eureka Conferences, USA. 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 book/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.

No. 9 Raffles Place

Office No. 26-01

Singapore 048619

Singapore

Email: subscriptions@benthamscience.net



CONTENTS

PREFACE	i
LIST OF CONTRIBUTORS	ii
CHAPTER 1 IMPORTANCE OF QUINONES IN DRUG DISCOVERY	1
<i>Priyanku Pradip Das, Hiyashree Sharmah, Lokman Ali Ahmed, Ashutosh Kumar</i>	
<i>Dash and Deepak Kumar</i>	
INTRODUCTION	2
CHEMISTRY OF QUINONE	3
PREVIOUS STUDIES ON QUINONES ANTIOXIDANT	4
ANTI-DIABETIC	5
ANTI-INFLAMMATORY	6
ANTI-ALZHEIMER	8
ANTI-MICROBIAL	10
CONCLUSION	13
REFERENCES	13
CHAPTER 2 CHEMISTRY AND SYNTHESIS OF QUINONES AND THEIR DERIVATIVES	18
<i>Divyani P. Patel, Satish Kumar Singh and Vivek Mishra</i>	
INTRODUCTION	18
Structure and Chemistry of Quinone	20
SYNTHESIS OF BENZOQUINONES	23
benzo-1,2-quinones	23
benzo-1,4-quinones	23
SYNTHESIS OF NAPHTHOQUINONES	26
Naphthoquinones and Benzoquinones Substitution	26
SYNTHESIS OF HETEROCYCLIC QUINONES	29
Five-membered Heteroaromatic Quinones	29
Six-membered Heteroaromatic Quinones	29
Saturated Heterocyclic Quinones	30
SYNTHESIS OF ANTHRAQUINONES	33
QUINONE DERIVATIVES	35
Quinone Tethered Amino Derivatives	36
Pentacenequinone Derivative	37
Naphthoquinone Derivatives	37
CONCLUDING REMARKS	44
REFERENCES	44
CHAPTER 3 IDENTIFICATION TECHNIQUES OF NATURAL AND SYNTHETIC QUINONES USING VARIOUS METHODS	52
<i>Satyanarayana Battula and Ashutosh Kumar Dash</i>	
INTRODUCTION	52
THE BIOLOGICAL, SYNTHETIC, AND INDUSTRIAL IMPORTANCE OF QUINONES	53
ANALYTICAL METHODS FOR THE DETERMINATION OF QUINONES	55
TITRIMETRIC METHODS FOR THE DETERMINATION OF QUINONES	55
SPECTROPHOTOMETRIC METHODS FOR THE DETERMINATION OF QUINONES	56
HPLC-BASED METHODS FOR THE DETERMINATION OF QUINONES	57
GC-MS-BASED METHODS FOR THE DETERMINATION OF QUINONES	59
CONCLUSION	60
REFERENCES	60
CHAPTER 4 QUINONE IN TRADITIONAL THERAPY AND NUTRACEUTICAL USE	64

INTRODUCTION	64
ANTIOXIDANT PROPERTIES	65
ANTI-INFLAMMATORY EFFECTS	65
ANTICANCER POTENTIAL	66
EXAMPLES OF QUINONE-CONTAINING PLANTS	68
TYPES OF QUINONES	69
TRADITIONAL THERAPEUTIC USES	69
BENZOQUINONES	69
ANTIMICROBIAL PROPERTIES	70
DISRUPTION OF CELL MEMBRANES	70
INHIBITION OF ENZYMATIC ACTIVITY	70
GENERATION OF REACTIVE OXYGEN SPECIES (ROS)	70
TRADITIONAL APPLICATIONS	70
WOUND HEALING	70
TOPICAL TREATMENTS	70
INTERNAL USE	71
PRESERVATION OF FOOD AND NATURAL PRODUCTS	71
NAPHTHOQUINONES	71
ANTI-INFLAMMATORY PROPERTIES	71
INHIBITION OF PRO-INFLAMMATORY ENZYMES	71
SUPPRESSION OF INFLAMMATORY CYTOKINES	71
ANTIOXIDANT ACTIVITY	72
TRADITIONAL ANTI-INFLAMMATORY APPLICATIONS	72
ARTHRITIS	72
SKIN INFLAMMATION	72
RESPIRATORY INFLAMMATION	72
ANTICANCER PROPERTIES	73
INDUCTION OF APOPTOSIS	73
INHIBITION OF CANCER CELL PROLIFERATION	73
ANTIMETASTATIC EFFECTS	73
MODULATION OF SIGNALING PATHWAYS	73
TRADITIONAL ANTICANCER APPLICATIONS	73
CANCER SUPPORT	73
TUMOR REDUCTION	73
GENERAL HEALTH TONIC	74
ANTHRAQUINONES	74
LAXATIVE EFFECTS	74
STIMULATION OF PERISTALSIS	74
INCREASED WATER AND ELECTROLYTE SECRETION	74
IRRITATION OF THE INTESTINAL MUCOSA	74
OTHER THERAPEUTIC USES	74
ANTICANCER	75
ANTIMICROBIAL	75
ANTI-INFLAMMATORY	75
ANTIOXIDANT	75
NUTRACEUTICAL USES	75
ANTIOXIDANT PROPERTIES	75
ANTI-INFLAMMATORY AND ANTICANCER PROPERTIES	76
ANTI-INFLAMMATORY PROPERTIES	76
INHIBITION OF PRO-INFLAMMATORY ENZYMES	76

SUPPRESSION OF INFLAMMATORY CYTOKINES	76
ANTIOXIDANT ACTIVITY	76
ANTICANCER PROPERTIES	76
EXAMPLES OF QUINONES WITH ANTI-INFLAMMATORY AND ANTICANCER PROPERTIES	77
NAPHTHOQUINONES	77
ANTHRAQUINONES	77
INCLUSION IN NUTRACEUTICALS	78
5. SAFETY AND TOXICITY	79
POTENTIAL TOXICITY OF QUINONES	79
1. OXIDATIVE STRESS	79
2. CYTOTOXICITY	80
3. GASTROINTESTINAL IRRITATION	80
4. HEPATOTOXICITY	80
5. ALLERGIC REACTIONS	80
ENSURING SAFETY: PROPER DOSAGE AND FORMULATION	81
1. DOSAGE REGULATION	81
2. STANDARDIZATION	81
3. FORMULATION	81
4. MONITORING AND GUIDELINES	81
5. RESEARCH AND DEVELOPMENT	82
CONCLUSION	82
REFERENCES	83
CHAPTER 5 EFFICIENT SYNTHESIS OF QUINONE-BASED GLYCOHYBRIDS	87
<i>Sunil Sharma, Yogesh Yadav, Ramesh Kumar and Ram Sagar</i>	
INTRODUCTION	87
SYNTHESIS OF QUINONE-BASED GLYCOHYBRIDS	90
CONCLUSION	123
REFERENCES	123
CHAPTER 6 PHARMACODYNAMICS OF QUINONES AND THEIR DERIVATIVES	130
<i>Ganesh Sonawane, Shashikant Bhandari, Ritu Gilhotra and Ashutosh Kumar Dash</i>	
INTRODUCTION	131
HISTORICAL BACKGROUND AND DISCOVERY	132
SIGNIFICANCE IN PHARMACOLOGY AND MEDICINE	132
CHEMICAL STRUCTURE AND CLASSIFICATION	132
Basic Chemical Structure of Quinones	132
Types of Quinones	133
Natural vs. Synthetic Quinones	134
Key Derivatives and their Unique Properties	135
MECHANISMS OF PHARMACODYNAMIC ACTION	135
Redox Properties and Electron Transfer	135
Generation and Role of Reactive Oxygen Species (ROS)	135
Interaction with Biomolecules (DNA, Proteins, Lipids)	136
Impact on Cellular Pathways	136
<i>Cellular Respiration and Mitochondrial Function</i>	136
<i>Signal Transduction Pathways</i>	136
PHARMACOKINETICS AND METABOLISM	137
Absorption and Bioavailability	137
Distribution in the Body	137
<i>Tissue and Organ Distribution</i>	137

<i>Blood-Brain Barrier Penetration</i>	137
<i>Metabolic Pathways</i>	137
<i>Role of Cytochrome P450 Enzymes</i>	138
Excretion Mechanisms	138
<i>Renal and Hepatic Routes</i>	138
<i>Half-life and Clearance</i>	138
THERAPEUTIC APPLICATIONS	138
Anticancer Activity	139
Examples of Quinone-Based Anticancer Drugs	139
Antibacterial and Antifungal Activities	139
Spectrum of Activity	139
Mechanisms of Microbial Inhibition	139
ANTIVIRAL POTENTIAL	140
Mechanisms of Antiviral Action	140
Emerging Applications in Viral Infections	140
OTHER THERAPEUTIC USES	140
Anti-inflammatory and Immunomodulatory Effects	140
Potential in Neuroprotection and Cardiovascular Diseases	141
TOXICOLOGY AND SIDE EFFECTS	141
Organ-specific Toxicities	141
COMMON ADVERSE EFFECTS	142
MITIGATION STRATEGIES	142
Dose Optimization	142
Use of Protective Agents	142
CLINICAL STUDIES AND TRIALS	143
Preclinical Research	143
<i>In vitro Studies</i>	143
Animal Models	143
CLINICAL TRIAL PHASES	144
Phase I: Safety and Dosage	144
Phase II: Efficacy and Side Effects	144
Phase III: Comparison to Standard Treatments	144
Phase IV: Post-marketing Surveillance	145
Case Studies	145
FUTURE PERSPECTIVES AND CHALLENGES	145
Current Challenges in Quinone-based Drug Development	145
<i>Stability and Solubility Issues</i>	145
Regulatory and Safety Considerations	146
Innovations and Emerging Research	146
<i>Novel Quinone Derivatives</i>	146
Advances in Drug Delivery Systems	147
Potential for Personalized Medicine	147
Future Trends and Research Directions	148
CONCLUSION	148
REFERENCES	149
CHAPTER 7 SYNTHETIC AND NATURAL QUINONES AS DRUG CANDIDATES	151
<i>Santosh Kumar Rath and Ashutosh Kumar Dash</i>	
INTRODUCTION	151
NATURAL NAPHTHOQUINONES	153

NATURAL NAPHTHOQUINONES WITH GREAT IMPORTANCE IN MEDICINAL CHEMISTRY	154
NEURODEGENERATIVE DISEASES	157
MITOCHONDRIAL DISORDERS	158
MUSCLE HEALTH AND EXERCISE PERFORMANCE	159
AGING AND SKIN HEALTH	160
NATURAL QUINONES AS ANTICANCER AGENTS	160
ANTHRACYCLINES	161
BIOACTIVITY	162
SYNTHETIC QUINONES AS DRUG CANDIDATES	163
SYNTHETIC QUINONES	163
CONCLUSION	163
REFERENCES	164
CHAPTER 8 UNDERSTANDING QUINONES WITH REFERENCE TO BIOCHEMISTRY	167
<i>Adil Ali, Mohd Hasan Mujahid, Ankit Paul and Tarun Kumar Upadhyay</i>	
INTRODUCTION	167
ISOLATION AND CHARACTERIZATION OF QUINONES	169
BIOSYNTHESIS OF QUINONES	171
BENZOQUINONES	172
NAPHTHOQUINONES	173
ANTHRAQUINONES	174
PHENANTHRAQUINONES	175
BIOCHEMICAL PROPERTIES	176
REDOX REACTION: OXIDATION AND REDUCTION STATES	176
QUINONE: A SIGNALING MOLECULES	177
PHARMACOLOGICAL ACTIVITY	178
PHARMACOKINETIC PROPERTIES	185
CONCLUSION	186
FUTURE PERSPECTIVE	186
ACKNOWLEDGMENT	187
REFERENCES	187
CHAPTER 9 QUINONE COMPOUNDS IN MEDICINE: A BIOLOGICAL PERSPECTIVE	195
<i>Rajendra Dighe, Ashutosh Kumar Dash, Shashikant Bhandari and Ritu Gilhotra</i>	
INTRODUCTION	196
HISTORICAL BACKGROUND AND DISCOVERY IN MEDICINE	197
Early uses and Discovery	197
19th Century: Isolation and Chemical Characterization	197
20th Century: Biomedical Discoveries	197
MODERN APPLICATIONS AND RESEARCH	198
OVERVIEW OF THE BIOLOGICAL IMPORTANCE OF QUINONES	198
Electron Transport and Cellular Respiration	199
Antioxidant Defense	199
Enzymatic Cofactors	199
Cellular Signaling	199
Detoxification and Stress Response	199
Anti-Cancer Properties	199
Photosynthesis in Plants	200
Microbial Metabolism	200
CHEMICAL STRUCTURE AND CLASSIFICATION	200
Types of Quinones	200

Benzoquinones	200
NAPHTHOQUINONES	201
ANTHRAQUINONES	203
KEY CHEMICAL PROPERTIES INFLUENCING BIOLOGICAL ACTIVITY	204
REDOX ACTIVITY	205
REACTIVE OXYGEN SPECIES (ROS) GENERATION	205
ALKYLATION ABILITY	205
ENZYME INHIBITION	206
CONJUGATION AND STABILITY	206
MECHANISMS OF ACTION	206
REDOX PROPERTIES OF QUINONES	206
REDUCTION-OXIDATION (REDOX) CYCLING	206
ELECTRON ACCEPTORS IN BIOLOGICAL SYSTEMS	206
PRODUCTION OF REACTIVE OXYGEN SPECIES (ROS)	207
ELECTRON TRANSFER AND RADICAL FORMATION	207
ELECTRON TRANSFER MECHANISMS	207
Quinone Reduction and Oxidation	207
Electron Acceptors in Biological Systems	207
RADICAL FORMATION AND ROS GENERATION	207
Production OF Reactive Oxygen Species (Ros)	207
<i>Radical Formation</i>	208
INTERACTION WITH CELLULAR COMPONENTS	208
Enzymatic Pathways Involving Quinones	208
QUINONES IN BIOLOGICAL SYSTEMS	208
ROLE OF QUINONES IN CELLULAR RESPIRATION	209
QUINONES AS CO-FACTORS IN ENZYMATIC REACTIONS	209
ENDOGENOUS QUINONES AND THEIR FUNCTIONS	210
THERAPEUTIC APPLICATIONS OF QUINONES	211
Anti-cancer Properties of Quinones	211
Mechanisms of Action	211
KEY QUINONE-BASED ANTI-CANCER DRUGS	211
Antimicrobial Properties	212
Mechanisms Against Bacteria, Fungi, and Viruses	212
EXAMPLES OF QUINONE-BASED ANTIMICROBIAL AGENTS	212
ANTI-INFLAMMATORY AND ANTIOXIDANT EFFECTS	213
KEY COMPOUNDS AND THEIR THERAPEUTIC POTENTIAL	213
OTHER MEDICAL APPLICATIONS	214
QUINONE COMPOUNDS IN DRUG DEVELOPMENT	214
Strategies for Designing Quinone-Based Drugs	215
STRUCTURE-ACTIVITY RELATIONSHIP (SAR) STUDIES	215
CHALLENGES IN DRUG DEVELOPMENT	216
Developing Quinone-Based Drugs Faces Several Challenges	216
CASE STUDIES OF SUCCESSFUL QUINONE-BASED DRUGS	216
TOXICOLOGICAL ASPECTS OF QUINONES	216
Potential Toxic Effects of Quinones	217
Mechanisms of Quinone-Induced Toxicity	217
DOSE-RESPONSE RELATIONSHIPS AND SAFETY PROFILES	217
STRATEGIES TO MITIGATE TOXICITY	218
QUINONES IN CLINICAL USE	218
Current Clinically Approved Quinone-Based Drugs	219
CLINICAL TRIAL DATA AND THERAPEUTIC OUTCOMES	219

Doxorubicin	219
Mitomycin C	219
Atovaquone	220
CASE STUDIES AND PATIENT MANAGEMENT	220
Case Study 1: Doxorubicin in Breast Cancer	220
Case Study 2: Mitomycin C in Bladder Cancer	220
FUTURE PROSPECTS AND EMERGING THERAPIES	221
FUTURE DIRECTIONS AND RESEARCH OPPORTUNITIES	221
Emerging Trends in Quinone Research	221
Novel Quinone Derivatives and Their Potential Applications	221
INTEGRATION OF QUINONE COMPOUNDS IN COMBINATION THERAPIES	222
ADVANCES IN DRUG DELIVERY SYSTEMS FOR QUINONE COMPOUNDS	222
Research Opportunities	223
CONCLUSION	223
REFERENCES	224

CHAPTER 10 RECENT STUDY ON QUINONE DERIVATIVES AND THEIR APPLICATIONS	228
<i>Suryakant R. Rode and Ashutosh Kumar Dash</i>	
INTRODUCTION	228
CLASSIFICATION OF QUINONES	229
Benzoquinones	229
Naphthoquinones	229
ANTHRAQUINONES	230
Heteroquinones	230
GENERAL PROCEDURE FOR DIAZAANTHRAQUINONE PREPARATION IN THE USE OF LI-ION BATTERIES	231
KEY FEATURES AND BENEFITS OF DIAZAANTHRAQUINONE DIMERS	231
MECHANISM OF OPERATION	231
APPLICATION OF LI8-BDAAQ IN LITHIUM-ION BATTERIES	232
ADVANTAGES OVER TRADITIONAL MATERIALS	232
CHALLENGES AND RESEARCH DIRECTIONS OF QUINONES IN SOME OTHER RESPECTS	232
QUINONES ENHANCE HUMIFICATION IN FOOD WASTE COMPOSTING	233
CONJUGATION OF CHLORO-QUINONE FORMING ADVANCED MOLECULE [4]	234
IDENTIFICATION OF ATROPISOMERS OF NAPHTHOQUINONE DERIVATIVE	234
Chromatogram of 2nd Isomer	235
APPLICATIONS OF CHLORIN-QUINONE CONJUGATES	235
As Fluorescent Probes and Sensors	235
Photodynamic Therapy (PDT)	236
QUINONE AND ITS DERIVATIVES HAVING CANCER-TREATING POTENTIAL	236
QUINONES AS ANTICANCER AGENTS DUE TO THEIR UNIQUE MECHANISMS OF ACTION IN ROS [5]	237
ALKYLATION AND CROSS-LINKING OF DNA	237
MODULATION OF SIGNAL TRANSDUCTION PATHWAYS	238
EXAMPLES OF QUINONES AS ANTICANCER AGENTS AS MARKETED PRODUCTS	238
QUINONES IN SUPRAMOLECULAR CHEMISTRY AND POLYMER CHEMISTRY	240
ONE-POT SYNTHESIS PROCEDURE OF BIS (ARYL AMINO) PENTIPTYCENES USING ANILINE [6]	240
ANALYTICAL DATA	240
APPLICATION OF BIS (ARYL AMINO) PENTIPTYCENES	242

PENTIPTYCENES USED IN MEDICINAL CHEMISTRY AS NDDS:	243
SOME OTHER APPLICATIONS OF QUINONES	243
USED IN ORGANIC CHEMISTRY SYNTHESIS	244
MECHANISM OF THE SYNTHESIS	244
CONCLUSION	245
REFERENCES	245
SUBJECT INDEX	248

PREFACE

Quinones constitute a major class of organic compounds that contain conjugated cyclic dione structures prevalent both in natural as well as synthetic organic chemistry. Naturally, quinones are rich in angiosperms, fungi (including lichens), bacteria, algae, ferns, conifers, sponges, *etc.*, and also in human beings. Hence, a lot of traditional Asian therapies include quinone as Ayurvedic medicine. These can be frequently accessed from reactive aromatic compounds, such as phenols or catechols, very easily. The topic “Quinone derivatives as drug candidates” is a vital point of discussion as they have a unique property to bind to multiple targets with excellent affinity. They are electrophilically reactive and covalently bind to nucleophilic sites within cells through the formation of oxidized cellular macromolecules, including lipids, proteins, and DNA. Hence, we can consider it as a privileged moiety for potential pharmacological activities. Due to its high redox ability, semiquinone radical can construct ROS (reactive oxygen species). Quinones are cast-off for electron and proton transport (Co-enzymes/ Cofactors) and are extremely tunable and versatile in function. With regard to biological activities, quinones and their derivatives have been proclaimed as antitumor, antibacterial, antifungal, antiviral, antimalarial, anti-AD, and anti-epileptic agents. They have various mechanisms of action for biological activities, including ROS, GSH, NADPH, P450s, (COX-2), glutathione S-transferase (GST), (NQO1), DNA, *etc.*, as receptors. If we collect quinone containing marketed drugs, we will get n-number. Some of them are Atovaquone, Flavolin, buparvaquone, Seratrodast, doxorubicin, Emodin, mitomycins, Duroquinone, Mitoxantrone, Porfiromycin, Parvaquone, Valrubicin, *etc.* Quinones assist as indicators that transform in physical presence, hence used as dyes. The negative side of quinone is also an important point of discussion, such as toxicity profile (quinone toxicity can arise because of their use as well as by the metabolism of other drugs and various environmental toxins or dietary constituents). Quinones as drugs can also be considered for organisms other than human beings, such as plants. Antifungal drugs include Chlonil, chlorothalonil, *etc.* Some naphthoquinones (Duniones) have been marketed as insecticides, pesticides, *etc.* Some drug-like molecules containing quinones are under FDA approval, *viz* vatiquinone from PTC Therapeutics, which will be used against epilepsy. The modern trends of quinones are discussed as a concluding chapter of the book.

Ashutosh Kumar Dash

R & D, Drug Discovery Division
Macleods Pharmaceuticals, India

&

Deepak Kumar

Department of Pharmaceutical Chemistry
School of Pharmaceutical Sciences, Shoolini University
Solan-173229, Himachal Pradesh
India

List of Contributors

Adil Ali	Department of Biotechnology, Parul Institute of Applied Sciences and Research and Development Cell, Parul University, Vadodara 391760, Gujarat-India
Ankit Paul	Department of Biotechnology, Parul Institute of Applied Sciences and Research and Development Cell, Parul University, Vadodara 391760, Gujarat-India
Ashutosh Kumar Dash	Senior Research Scientist (R&D), Drug Discovery Division, Macleod Pharmaceuticals Ltd, Mumbai, India
Deepak Kumar	Department of Pharmaceutical Chemistry, School of Pharmaceutical Sciences, Shoolini University, Solan-173229, Himachal Pradesh, India
Divyani P. Patel	Department of Chemistry, Government College Daman (Affiliated to Veer Narmad South Gujarat University, Surat), Daman, U.T. of Dadra & Nagar Haveli and Daman & Diu, Gujarat 395007, India
Hiyashree Sharmah	Department of Pharmaceutical Chemistry, NETES Institute of Pharmaceutical Science (NIPS), Nemcare Group of Institution, Mirza, Kamrup Assam 781125, India
Lokman Ali Ahmed	Department of Pharmaceutical Chemistry, NETES Institute of Pharmaceutical Science (NIPS), Nemcare Group of Institution, Mirza, Kamrup Assam 781125, India
Mohd Hasan Mujahid	Department of Biotechnology, Parul Institute of Applied Sciences and Research and Development Cell, Parul University, Vadodara 391760, Gujarat-India
Priyanku Pradip Das	Department of Pharmaceutical Chemistry, School of Pharmaceutical Sciences, Shoolini University, Solan-173229, Himachal Pradesh, India
Ramesh Kumar	Department of Chemistry, Kurukshetra University Kurukshetra, Haryana 136119, India
Ram Sagar	Glycochemistry Laboratory, School of Physical Sciences, Jawaharlal Nehru University, New Delhi 110067, India
Rajendra Dighe	KBHSS Trust's, Institute of Pharmacy, Malegaon, Maharashtra, India
Ritu Gilhotra	Gyan Vihar School of Pharmacy, Suresh Gyan Vihar University, Jaipur, Rajasthan, India
Satish Kumar Singh	Department of Chemistry, Government College Daman (Affiliated to Veer Narmad South Gujarat University, Surat), Daman, U.T. of Dadra & Nagar Haveli and Daman & Diu, Gujarat 395007, India
Satyanarayana Battula	Department of Chemistry, Central University of Jammu, Jammu & Kashmir, 181143, India
Shashikant Bhandari	AISSMS College of Pharmacy, Pune, Maharashtra, India
Suryakant R. Rode	Jai Research Foundation Valvada, Valsad, Gujrat, India
Santosh Kumar Rath	School of Pharmaceuticals and Population Health Informatics, Faculty of Pharmacy, DIT University, Dehradun, Uttarakhand-248009, India

Sunil Sharma	Glycochemistry Laboratory, School of Physical Sciences, Jawaharlal Nehru University, New Delhi 110067, India
Tarun Kumar Upadhyay	Department of Biotechnology, Parul Institute of Applied Sciences and Research and Development Cell, Parul University, Vadodara 391760, Gujarat-India
Vivek Vivek	Amity Institute of Click Chemistry Research and Studies, Amity University Uttar Pradesh, Noida 201313, UP, India
Yogesh Yadav	Glycochemistry Laboratory, School of Physical Sciences, Jawaharlal Nehru University, New Delhi 110067, India

CHAPTER 1

Importance of Quinones in Drug Discovery

Priyanku Pradip Das¹, Hiyashree Sharmah², Lokman Ali Ahmed², Ashutosh Kumar Dash^{3,*} and Deepak Kumar^{1,*}

¹ Department of Pharmaceutical Chemistry, School of Pharmaceutical Sciences, Shoolini University, Solan-173229, Himachal Pradesh, India

² Department of Pharmaceutical Chemistry, NETES Institute of Pharmaceutical Science (NIPS), Nemcare Group of Institution, Mirza, Kamrup Assam 781125, India

³ Senior Research Scientist (R&D), Drug Discovery Division, Macleod Pharmaceuticals Ltd, Mumbai, India

Abstract: Quinones, which are cyclic chemical molecules, have attracted considerable interest in the field of drug discovery because of their wide range of pharmacological effects and structural flexibility. This study examines the diverse functions of quinones in several therapeutic domains, encompassing their antioxidant, anti-diabetic, anti-inflammatory, anti-Alzheimer, and antibacterial properties. Having redox activity means that quinones can change important signalling pathways and create reactive oxygen species (ROS). This makes them effective against cancer cells and also protects against damage caused by oxidative stress. In preclinical studies, both natural and artificial quinone derivatives have publicised promising results. They act as antioxidants, getting rid of free radicals and stopping lipid peroxidation. Moreover, quinones have shown promise in the treatment of diabetes by blocking crucial enzymes and decreasing high blood sugar levels after meals. Quinones have anti-inflammatory properties because they are involved in the diminution of pro-inflammatory mediators and reduce oedema volume. Quinone derivatives have demonstrated reduction of β -amyloid aggregation, acetylcholinesterase activity, and monoamine oxidase in Alzheimer's disease research, suggesting them as possible multitarget-directed ligands for Alzheimer's disease treatment. Quinones also have antibacterial action against a variety of harmful microorganisms, indicating that they have the potential to tackle infectious disorders. Overall, quinones and their derivatives represent attractive possibilities for drug development across diverse therapeutic domains, emphasising their importance in advancing pharmaceutical research and solving unmet medical needs.

Keywords: Quinone, drug, drug discovery, disease.

* **Corresponding author Ashutosh Kumar Dash and Deepak Kumar:** Senior Research Scientist (R&D), Drug Discovery Division, Macleod Pharmaceuticals Ltd, India and Department of Pharmaceutical Chemistry, School of Pharmaceutical Sciences, Shoolini University, Solan-173229, Himachal Pradesh, India; E-mails: ashutosh.dash10@gmail.com and guptadeepak002@gmail.com

Ashutosh Kumar Dash & Deepak Kumar (Eds.)
All rights reserved-© 2025 Bentham Science Publishers

INTRODUCTION

The quest for novel therapeutic agents to address the myriads of human ailments necessitates exploration into diverse chemical classes. Quinones, owing to their unique structural attributes and pharmacological properties, have garnered considerable attention in drug discovery endeavours. Quinones exhibit a wide array of biological activities, making them versatile candidates for drug development [1, 2]. Quinones are capable of interacting with various cellular components, such as proteins and enzymes, due to their redox activity, thereby influencing essential signalling pathways. Furthermore, their ability to undergo redox cycling makes them effective generators of reactive oxygen species (ROS), which can induce cytotoxic effects in cancer cells. Additionally, quinones possess intrinsic antioxidant properties, enabling them to scavenge free radicals and alleviate oxidative stress-induced damage. This dual functionality of quinones, serving both as prooxidants and antioxidants, highlights their intricate role in cellular homeostasis and the pathogenesis of diseases [3]. It is well documented that quinone moiety in vitamins K₁ and K₂ is chiefly responsible for various biological activities [4]. Furthermore, quinones have been implicated in the inhibition of key enzymes involved in disease progression, such as topoisomerases and kinases, highlighting their potential as therapeutic agents. In addition to their direct pharmacological effects, quinones can also serve as versatile pharmacophores for drug discovery [5]. Quinones play multifaceted roles in cellular processes and pharmacology. Acting as electron carriers in cellular respiration and oxidative phosphorylation, they facilitate energy production. Additionally, quinones act as electrophiles, forming covalent bonds with nucleophilic residues in target proteins, a mechanism commonly exploited in designing enzyme inhibitors. Moreover, they participate in Michael addition reactions, enabling the conjugation of biologically active moieties to the quinone scaffold, thus imparting additional pharmacological properties. Beyond pharmacology, quinones are indispensable across scientific domains serving in electron transfer and photochemical processes with applications ranging from catalysts to energy storage [6]. Found abundantly in nature, sourced from plants, animals, bacteria, and fungi, they serve as building blocks for various technological advancements [7, 8]. In the pharmaceutical industry, quinone derivatives are crucial in drug development, offering promising pharmacological effects, including anticancer, antioxidant, antimicrobial, and anti-inflammatory activities. They form a major class of anticancer cytotoxins. One example is daunorubicin, which is antileukemic [9]. Additionally, in herbal medicine, quinone derivatives contribute to remedies for ailments, such as purgative (sennosides), antimicrobial and antiparasitic (rhein and saprorthoquinone, atovaquone), anti-tumor (emodin and juglone), and anti-cardiovascular disease (tanshinone), as well as in the inhibition of PGE₂ biosynthesis (arnebione and

arnebifuranone). Furthermore, the natural world offers intriguing discoveries, such as *Malbranchea cinnamomea*, a thermophilic fungus capable of producing quinone antibiotics, highlighting the potential for novel pharmaceutical interventions derived from these compounds [10].

Quinones and their derivatives are essential and adaptable compounds that have far-reaching implications across scientific fields. Their multifaceted characteristics, spanning from fundamental chemical processes to advanced medical applications, underscore their enduring significance in advancing knowledge and meeting societal needs. In drug discovery, their wide-ranging biological activities, redox capabilities, structural flexibility, and potential as pharmacophores offer promise for creating innovative therapies for diverse diseases, including cancer, infectious diseases, and neurodegenerative disorders. Consequently, quinones remain pivotal in shaping and innovating various disciplines, showcasing their profound influence on both science and society.

CHEMISTRY OF QUINONE

Quinones constitute a group of cyclic organic compounds featuring a six-membered unsaturated ring where two oxygen atoms are bonded as carbonyl groups [11]. Quinone-based compounds exhibit thermal stability due to their aromatic ring structure, which enables them to maintain their integrity under heat. These compounds display reactivity because of the electron-rich regions present within their molecular structure. Additionally, the inclusion of oxygen atoms as heteroatoms enhances their reactivity against disease-causing microorganisms. Their ring structure being electron-rich allows them to undergo electrophilic substitution reactions, while the ketonic carbonyl carbon's electron deficiency adds to their versatility. This dual nature makes quinones highly active and promising candidates for fighting various disease conditions. Moreover, their propensity to undergo tautomerization, transitioning between quinone and hydroquinone forms, contributes to their variability in properties and reactivity [12]. When quinones are combined with heteroatoms like nitrogen, halogens, or sulphur to create medicinal compounds, they tend to exhibit enhanced bioactivity compared to standard molecules. The presence of these heteroatomic groups on the quinone structure introduces electron-donating or electron-withdrawing effects through resonance and inductive effects. This alters the reactivity of the compound, consequently influencing its pharmacokinetics and pharmacodynamics [13]. According to the Hammett equation concept, these effects lead to qualitative and quantitative changes in the activity of the compounds. Such changes in activity are attributed to variations in the sigma and rho values of the additional groups present in the compound, as well as their positioning and stereochemistry [14].

CHAPTER 2

Chemistry and Synthesis of Quinones and their Derivatives

Divyani P. Patel¹, Satish Kumar Singh^{1,*} and Vivek Mishra^{2,*}

¹ Department of Chemistry, Government College Daman (Affiliated to Veer Narmad South Gujarat University, Surat), Daman, U.T. of Dadra & Nagar Haveli and Daman & Diu, Gujarat 395007, India

² Amity Institute of Click Chemistry Research and Studies, Amity University Uttar Pradesh, Noida 201313, UP, India

Abstract: Quinones are a group of organic compounds that have a wide range of chemical properties and applications in various fields, such as pharmaceuticals, materials science, and organic synthesis. They are highly versatile and can be modified to produce derivatives with unique properties. This chapter presents a comprehensive and current overview of the chemistry and synthesis of quinones and their derivatives. It serves as an invaluable resource for chemists, researchers, and scientists who are interested in exploring the diverse aspects of this significant class of organic compounds.

Keywords: Derivatives of quinone, Synthesis of quinone, Quinone.

INTRODUCTION

Quinones are fascinating chemical structures composed of a nonaromatic ring and two carbonyl functional groups positioned at either the 1 & 2 or 1 & 4 relative to one another [1 - 4]. Quinones have garnered significant scientific attention since their fundamental structure was revealed in 1838 [5, 6].

Quinones have a crucial function in photosynthesis by carrying electrons. They are a type of molecule that works as vitamins and can help prevent and treat various illnesses, such as cardiovascular diseases and osteoporosis. Quinones can also enhance overall health conditions due to their antioxidant properties [7]. Several cancer-fighting drugs that have either been clinically approved or are

* Corresponding authors Satish Kumar Singh & Vivek Mishra: Department of Chemistry, Government College Daman (Affiliated to Veer Narmad South Gujarat University, Surat), Daman, U.T. of Dadra & Nagar Haveli and Daman & Diu, India; Amity Institute of Click Chemistry Research and Studies, Amity University Uttar Pradesh, Noida 201313, UP, India E-mail: vmishra@amity.edu; drsatish.singh@ddd.gov.in

currently in clinical trials are made up of quinone-related compounds. Quinones, which can be produced from air pollutants, also have toxicological effects.

Quinones can activate rapid redox cycles, which enables them to form bonds with hydroxyl, thiol, and amine groups [8]. Furthermore, several quinones have anti-inflammatory [9, 10], anti-osteoarthritis [11], antibiotic [12], antimicrobial [13], antioxidant [14], and anticancer potential (Fig. 1) [14-16]. While the exact mechanism by which they operate remains incompletely elucidated, speculation suggests that DNA is their primary target. Some proteins participate in alkylation or intercalation with DNA, while others catalyze double-strand DNA breaks and also serve in DNA cleavage through the actions of both DNA topoisomerase I and II [17].

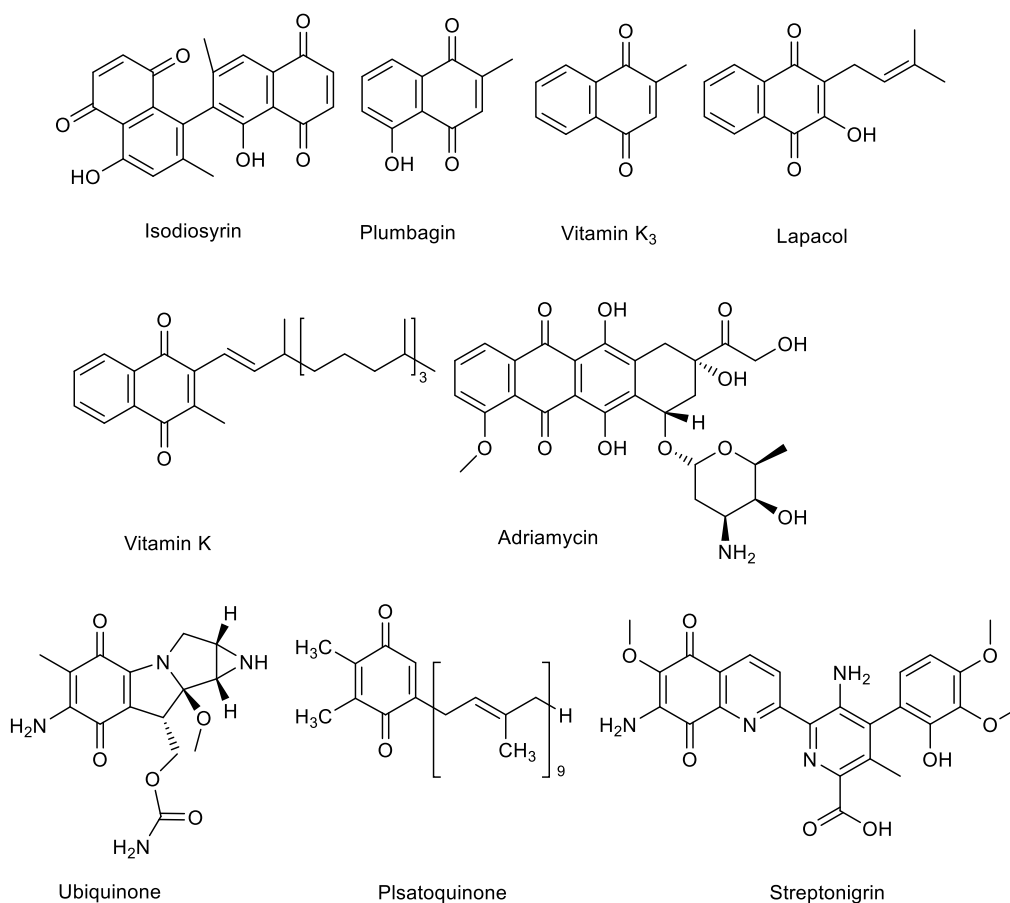


Fig. (1). Some naturally occurring quinone derivatives [25 - 27].

Quinones and their derivatives are essential in chemical, environmental, and pharmaceutical applications because of their distinct physical and chemical characteristics [18]. Quinones and their derivatives possess unique physical and chemical properties that make them essential for chemical, environmental, and pharmaceutical applications [19 - 21].

Furthermore, quinones serve as key components in the synthesis of functional materials, such as conducting polymers, organic dyes, and photoactive molecules, enabling applications in optoelectronics, photovoltaics, and sensor technologies [22]. Their redox chemistry has also been harnessed for energy storage devices, electrochemical sensors, and catalytic transformations, underscoring the multifaceted nature of quinone reactivity and its relevance to modern technological challenges [23, 24].

In this chapter, we explore the chemistry of quinones and their derivatives, underlying their reactivity, synthetic strategies for their preparation, and the myriad applications that exploit their unique properties. Through a comprehensive examination of quinone chemistry, we aim to illuminate the diverse facets of this fascinating class of compounds and highlight their enduring impact on science and technology.

Structure and Chemistry of Quinone

Quinones are colored compounds with a basic benzoquinone chromophore structure consisting of two carbonyl functional groups associated with two C=C bonds. Anthraquinones, benzoquinones, and naphthoquinones are the three primary classes of quinones, distinguished by their respective one, two, and three-ring structures. Benzoquinone is an essential component of quinones; specifically, 1,4-benzoquinone (4-benzoquinone) is a non-aromatic substance that may be readily reduced to produce hydroquinone [28]. Benzoquinone units play a crucial role as fundamental units in both the biosynthesis of biologically active chemicals and quinone synthesis. Anthraquinones are compounds characterized by the attachment of 1,4-benzoquinones to one or more C₆H₆ rings on a 2,3-carbon position. Two carbonyl groups are located at a single benzene ring in the naphthoquinone structure, usually in the ortho or para position [29, 30]. Naphthoquinones hold α - and β -unsaturated carbonyl functional groups. The electron delocalization facilitated by the presence of carbonyl groups and double bonds results in strong coloring in the visible spectrum. Anthraquinones, which belong to the third family of quinones, are molecules that consist of the anthracene nucleus and two carbonyl groups, often located on the B-ring. Due to the ability of quinone structures to accommodate various substitution patterns, there are several derivatives found in nature, particularly for anthraquinones.

CHAPTER 3

Identification Techniques of Natural and Synthetic Quinones Using Various Methods

Satyanarayana Battula^{1,*} and Ashutosh Kumar Dash²

¹ Department of Chemistry, Central University of Jammu, Jammu & Kashmir, 181143, India

² Senior Research Scientist (R&D), Drug Discovery Division, Macleod Pharmaceuticals Ltd, Mumbai, India

Abstract: Quinones are intriguing substances with distinctive properties and several significant biological and chemical functions and applications. Quinones are found in many parts of nature, including the tissues of plants and animals. They have several important roles in biological systems, for example, in the electron transport process to preserve plants' and animals' biological processes, in the form of plastoquinone and phyloquinone to be a part of photosynthesis in plants, and in the posttranslational modification of proteins and others. On essentiality grounds, they need to be detected and determined from the natural and synthetic samples. This chapter incorporates the detection and determination methods for various natural and synthetic quinones, viz., titrimetric methods, spectrophotometric methods, HPLC-based methods, and GC-M-based methods.

Keywords: GC-MS, HPLC, Titrimetric methods, Quinones.

INTRODUCTION

A special class of chemical molecules known as quinones is generated from aromatic compounds such as naphthalene or benzene. Quinones are composed of two carbonyl bonds formed when two oxygen atoms are replaced by two hydrogen atoms in a six-membered core benzene ring [1]. Quinones are a class of biological pigments that are present in many different types of living things, including fungi, bacteria, higher plants, and a few mammals [2]. They can be found in nature in a variety of forms, including polycyclic quinones, benzoquinones, naphthoquinones, and anthraquinones. Quinones have displayed multiple applications, including biological (antibacterial, anticancer, antimalarial, antioxidant, and anti-inflammatory properties) [3]. They are used as natural colorants in the fabric industry as they exert antifungal, anti-insecticide, anti-

* Corresponding author Satyanarayana Battula: Department of Chemistry, Central University of Jammu, Jammu & Kashmir, 181143, India; E-mail: satyamssd@gmail.com

bacterial, and anti-UV properties to the fabric, particularly for the textile industry [2]. Their low cost, sustainability, and strong environmental stability make them an attractive material for supercapacitors [4]. They are used as an oxidant in several organic oxidations in the form of *p*-quinone oxidations (DDQ and chloranil for hydride abstraction) [5]. They also have biological functions (oxidative phosphorylation [6], electron transport, and bioenergetic transport processes) [7] and are used as cathodic materials for lithium-ion batteries as their ability to undergo reversible self-redox reaction makes them indispensable for efficient energy storage [8].

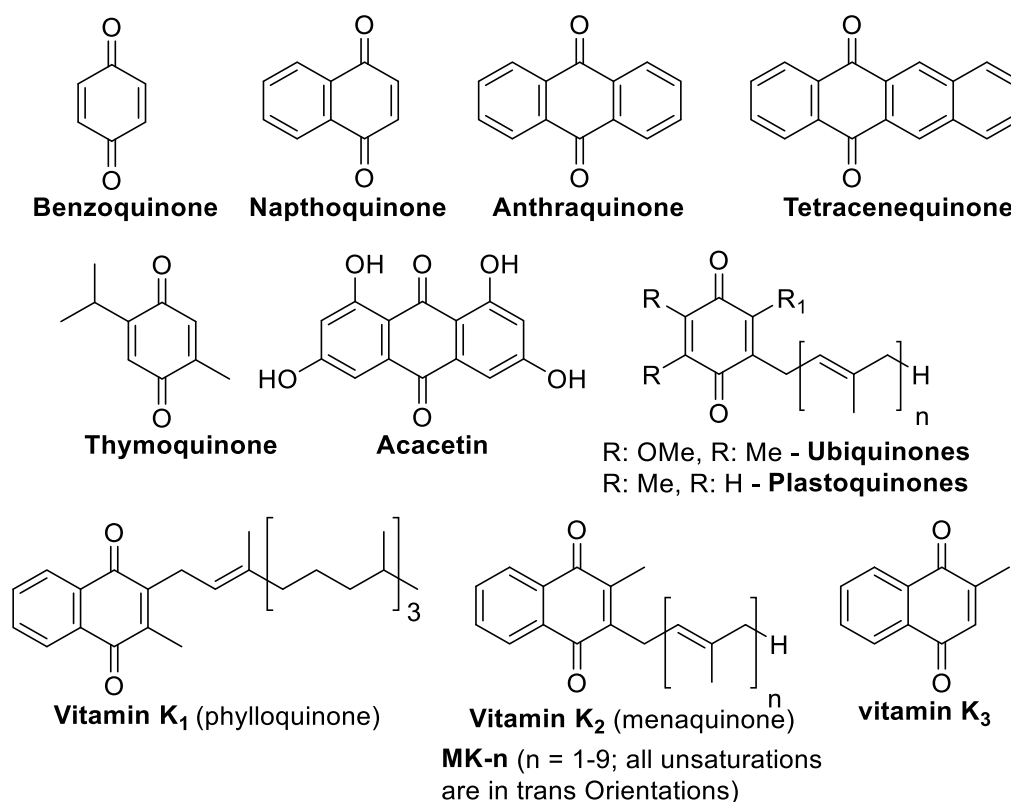


Fig. (1). Different quinone structures.

THE BIOLOGICAL, SYNTHETIC, AND INDUSTRIAL IMPORTANCE OF QUINONES

The quinones are one of the important classes of natural molecules with a variety of useful applications in biological systems. Almost all types of aerobic species, including bacteria, higher plants, and animals, contain ubiquinones (n = 1–12). They are present in mitochondria and play a major role in the electron transport

mechanism in the respiratory chain [9]. On the other hand, chloroplasts of green plants encompass plastoquinones (plastoquinone; $n=9$), which are generally involved in electron transport pathways during photosynthesis [10]. In addition, vitamin K consists of a structurally related class of 2-methyl-1,4-naphthoquinone derivatives with the side chains containing either isoprenoid units (menaquinones (MKs), vitamin K_2) or a side chain containing phytyl unit (phyloquinone; vitamin K_1) [11]. It was previously established that vitamin K is advantageous for bone formation, metabolism, and blood coagulation [12]. Additionally, vitamin K displays imperative clinical applications like treating osteoporosis, arterial calcification [13], and vitamin K insufficiency. There are other anthraquinone molecules, for example, doxorubicin (DXR) antibiotic, which have been utilized in the clinical treatment of malignant tumors [14]. Rhein (the main active ingredient in rhubarb, a traditional Chinese herb) is an immunosuppressive and anti-inflammatory molecule [15].

Adversely, quinones have also been considered a class of toxins that can have a wide range of harmful effects on living cells; for instance, they produce reactive oxygen species (ROS) in biological systems through their redox cycle, initiating several types of oxidative damage; for example, to DNA, proteins, and others [16, 17]. Moreover, the atmosphere contains polycyclic aromatic hydrocarbon quinones (PAHQ), as it is believed that the photo-oxidation of polycyclic aromatic hydrocarbons takes place, which are generally discharged by motor vehicle engines into the environment. These PAHQs cause the pathogenesis of respiratory diseases [18].

Apart from the wide spectrum of biological interests, quinones and their derivatives have been proven to exhibit extensive applications in diverse fields owing to their special chemical characteristics. Quinone has been employed as a dienophile in a stream of Diels-Alder reactions [19] as Michael donors/acceptors and 1,3-dipolarophiles [20] for decades and used in the synthesis of several natural products and stereo-selective complex molecules. In addition, ortho-quinone methides are imperative synthetic intermediates and used in enantioselective nucleophilic addition reactions [21]. As quinones have an additional nature to undergo reversible reduction and oxidation reactions, they are essential for effective energy storage devices and battery making [22]. Anaquinone, 1,4-naphthoquinone (NQ), and 1,4-benzoquinone are important organic cathodes that have already been used in a number of metal-organic systems, and they are capable materials for the making of multivalent batteries such as Li, Na, K, Mg, Al, and others [23].

Quinone in Traditional Therapy and Nutraceutical Use

Santosh Kumar Rath^{1,*} and Ashutosh Kumar Dash²

¹ School of Pharmaceuticals and Population Health Informatics, Faculty of Pharmacy, DIT University, Dehradun, Uttarakhand-248009, India

² Senior Research Scientist (R&D), Drug Discovery Division, Macleod Pharmaceuticals Ltd, Mumbai, India

Abstract: Quinones are a distinct group in chemistry, having a wide range of chemical and biological properties. These are extensively cast off as traditional medicines, such as anticancer, anti-inflammatory, antibacterial, *etc.* Plants such as Henna, Rhubarb, and Aloe vera possess quinones as active ingredients, which developed diverse medicinal possessions. Traditional uses and nutraceutical ethics have been enriched owing to the molecule. The biological application of quinones is discussed.

Keywords: Biological use, Nutraceuticals, Traditional use, Quinone.

INTRODUCTION

Quinones are a prominent class of organic compounds that hold significant importance in a multitude of biological processes. They are characterized by their fully conjugated cyclic dione structure, which consists of a ring system with two ketone (carbonyl) groups. This unique structure allows quinones to participate in various redox reactions, making them essential in biochemical pathways [1]. Quinones are naturally abundant, especially in the plant kingdom, where they play critical roles in photosynthesis, respiration, and defense mechanisms.

Historically, quinones have been utilized in traditional medicine for centuries. Their presence in medicinal plants has been exploited for their therapeutic properties long before the advent of modern pharmaceuticals. For example, quinones like coenzyme Q10 are vital for cellular energy production, while others, such as vitamin K, are crucial for blood clotting processes [2].

* **Corresponding author Santosh Kumar Rath:** School of Pharmaceuticals and Population Health Informatics, Faculty of Pharmacy, DIT University, Dehradun, Uttarakhand-248009, India; E-mails: skrath1985@gmail.com and santoshk.rath@dituniversity.edu.in

In recent years, the scientific community has shown a growing interest in the potential of quinones as nutraceuticals. These compounds are widely distributed

in nature and found in various plants, fungi, bacteria, and marine organisms. The natural occurrence and biological significance of quinones make them valuable candidates for nutraceutical applications, offering potential health benefits beyond basic nutrition [3]. Nutraceuticals are food-derived products that offer health benefits beyond basic nutrition. The interest in quinones is largely due to their impressive range of bioactive properties, including antioxidant, anti-inflammatory, and anticancer activities. Ongoing research and development are essential to fully understand their mechanisms of action, optimize their bioavailability, and integrate them effectively into nutraceutical products. As science continues to uncover the therapeutic potential of quinones, their role in promoting health and preventing disease is likely to expand, making them an exciting area of focus in the nutraceutical industry [4].

ANTIOXIDANT PROPERTIES

Quinones are renowned for their ability to neutralize free radicals, thereby preventing oxidative stress and cellular damage and protecting biological systems from damage. This antioxidant property is particularly crucial in defending cells from the harmful effects of reactive oxygen species (ROS), which are linked to aging and various chronic diseases [5]. Quinones can substitute between their oxidized (quinone) and reduced (hydroquinone or semiquinone) forms. This redox cycling allows quinones to act as electron acceptors and donors, neutralizing ROS and preventing oxidative damage to cellular components. Quinones can directly scavenge free radicals, such as superoxide anions, hydroxyl radicals, and peroxyl radicals [6]. By donating electrons or hydrogen atoms, quinones neutralize these reactive species, reducing their potential to cause cellular damage. Some quinones can chelate transition metals like iron and copper, which are catalysts in the formation of highly reactive hydroxyl radicals *via* the Fenton reaction. By binding these metals, quinones prevent the catalysis of ROS production. The ability of quinones to undergo redox cycling, scavenge free radicals, and chelate metals underpins their effectiveness as antioxidants.

ANTI-INFLAMMATORY EFFECTS

Inflammation is a biological response to harmful stimuli, but chronic inflammation can lead to various health issues, including autoimmune diseases and cancer. Quinones have been found to exhibit anti-inflammatory effects by modulating pathways that reduce inflammation and inhibit the production of pro-inflammatory cytokines. Quinones can suppress the production of pro-inflammatory cytokines such as tumor necrosis factor-alpha (TNF- α), interleukins

(IL-1 β , IL-6), and interferon-gamma (IFN- γ) [7, 8]. This inhibition helps reduce the overall inflammatory response. NF- κ B is a key transcription factor that regulates the expression of various inflammatory genes. Quinones can inhibit the activation of NF- κ B, thereby reducing the expression of pro-inflammatory cytokines, chemokines, and adhesion molecules [9]. Quinones can inhibit the activity of COX and LOX enzymes, which are involved in the synthesis of pro-inflammatory eicosanoids such as prostaglandins and leukotrienes [10]. This suppression leads to reduced inflammation and pain. The nuclear factor erythroid 2-related factor 2 (Nrf2) pathway plays a critical role in the cellular antioxidant response. Quinones can activate Nrf2, leading to the upregulation of antioxidant enzymes and suppression of inflammation. Quinones can affect the MAPK signaling pathways, which are involved in the regulation of inflammatory responses [11]. By modulating these pathways, quinones help in reducing the expression of inflammatory mediators. Their ability to modulate key inflammatory pathways, such as NF- κ B, COX, LOX, Nrf2, and MAPK, underpins their effectiveness as anti-inflammatory agents.

ANTICANCER POTENTIAL

The anticancer properties of quinones are among the most promising. They can induce apoptosis (programmed cell death) in cancer cells, inhibit cell proliferation, and interfere with tumor growth and metastasis. These effects are mediated through various mechanisms, including the generation of ROS to selectively target cancer cells and the inhibition of key signaling pathways involved in cancer progression. Due to these multifaceted properties, quinones are being extensively studied for their potential applications in health and medicine. Their role as antioxidants, anti-inflammatory agents, and anticancer compounds highlights their importance in the development of new therapeutic strategies and health supplements [12, 13]. As research continues to uncover the diverse benefits of quinones, their incorporation into modern healthcare and nutraceutical products is likely to expand, offering new avenues for enhancing human health and well-being. Some quinones can intercalate into the DNA double helix, disrupting the DNA structure and interfering with DNA replication and transcription. Certain quinones can form covalent bonds with DNA, causing DNA alkylation. This can lead to DNA cross-linking and strand breaks, further inhibiting DNA synthesis and triggering cell death mechanisms. Topoisomerases are enzymes that regulate the overwinding or underwinding of DNA during replication and transcription [14, 15]. Quinones, such as anthraquinones like doxorubicin, can inhibit topoisomerase II, preventing the enzyme from re-ligating DNA strands after they have been cut. This inhibition results in the accumulation of DNA breaks, leading to apoptosis [16]. Quinones can modulate the cellular redox balance by interacting with cellular thiols and other antioxidant systems. This disruption can deplete

CHAPTER 5

Efficient Synthesis of Quinone-Based Glycohybrids

Sunil Sharma¹, Yogesh Yadav¹, Ramesh Kumar² and Ram Sagar^{1,*}

¹ Glycochemistry Laboratory, School of Physical Sciences, Jawaharlal Nehru University, New Delhi 110067, India

² Department of Chemistry, Kurukshetra University Kurukshetra, Haryana 136119, India

Abstract: Quinones are redox-active cyclic chemical compounds with two carbonyl groups in a six-membered ring structure, either contiguous or apart. Quinones are a diverse group of natural compounds that have gained attention for their pharmacological properties. This book chapter focuses on the design and synthesis of natural product-inspired quinone-based glycohybrids. Glycohybrids can have a broad variety of structural and functional properties, including protein-carbohydrate interactions that are essential for the biology of mammals and some disease states. These glycohybrids are designed based on the structures of bioactive aryl glycosides and quinones, aiming to enhance their binding affinity, enhanced bioavailability, high water solubility, low toxicity, and specificity toward cancer-related protein targets. This book chapter consists of the literature from January 2017 to December 2023 and provides an overview of recent developments in the chemical synthesis of glycohybrids based on natural product scaffold of quinones.

Keywords: 1,4-naphthoquinone, Anticancer, Antiradical, Click chemistry glycohybrids, Cytotoxicity, Glycohybrids, Natural products, Synthetic methods, Quinone.

INTRODUCTION

Quinones are colored substances containing a basic benzoquinone chromophore composed of two carbonyl groups joined by two carbon-carbon double bonds. The quinone dyes are composed of fused benzenoid quinoid ring complexes that have enough conjugation to provide color. The three primary classes of quinones are benzoquinones (**A**), benzoquinones (**B**), and anthraquinones (**C**), which have 1, 2, and 3-ring structures, respectively, as shown in (Fig. 1). The fundamental building block of quinone molecules is benzoquinone [1]. Chemically, 1,4-benzoquinone, commonly known as para-benzoquinone, is a non-aromatic substance that reduces readily to hydroquinone [2]. Benzoquinone units are

* Corresponding author Ram Sagar: Glycochemistry Laboratory, School of Physical Sciences, Jawaharlal Nehru University, New Delhi 110067, India; E-mail: ram.sagar@jnu.ac.in

essential moieties to produce biologically active chemicals and act as building blocks in quinone synthesis [1].

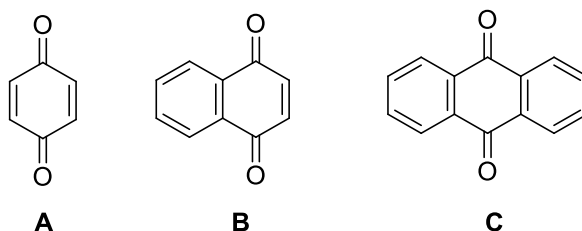


Fig. (1). Chemical structure of benzoquinone **A**, naphthoquinone **B**, and anthraquinone **C**.

Naphthoquinones are compounds that have para-benzoquinones bound to an additional benzene ring at position 2,3-C (carbon). Two carbonyl groups are present on one benzene ring in the naphthoquinone structure (Fig. 1b), usually in the o- or p-orientation [3]. Naphthoquinones also have α - and β -unsaturated carbonyls. The visible region exhibits significant coloration due to extended electron delocalization across carbonyl groups and double bonds [4].

Nature is full of naphthoquinones [5, 6], which are typically found as glycosides that may be separated from bacteria, fungi, plants, and marine invertebrates [7, 8]. The pharmacological activity [9 - 11] and diverse synthesis techniques of naphthoquinones, including their anticancer, antibacterial, antifungal, and anti-inflammatory properties, have been documented in recent years [12 - 14]. The solubility and activity of naphthoquinones will increase as they convert to naphthoquinone glycosides, and new activity may even develop, offering a new method for obtaining novel compounds with a range of biological activities [15 - 17]. According to reports, the anticancer activities of 1,4-naphthoquinone could be enhanced by the inclusion of acetylated D-glucose and D-galactose residues [18a-b]. One example of this would be the acetylated glycosides of lapachol [19]. Thus, the synthesis of 1,4-naphthoquinone glycosides is a powerful approach to finding novel compounds with strong biological activity [20].

The third class of quinones, known as anthraquinones, are compounds containing the anthracene nucleus with two carbonyl groups. They are derived from the tricyclic aromatic chemical molecule 9,10-dioxoanthracene ($C_{14}H_8O_2$) (Fig. 1), which has a fundamental structure. Anthraquinones are found in fungi, lichens, and plants. Hydroxyanthraquinoids absorb visible light and are therefore colored. Alizarin is a prominent red dye used in the fabric industry. It has anthraquinone moiety.

There are hundreds of derivatives in nature due to quinone structures' ability to accommodate various substitution sequences, particularly for anthraquinones. A

quinone compound's color is often determined by the location, kind, and quantity of hydroxyl and electron-donating/accepting elements, commonly known as auxochromes, as well as by the many rings that affect steric effects and intramolecular hydrogen bonding.

Quinones are important secondary metabolites that play a crucial role in photosynthesis and respiration processes in plants. These activities include electron transport and oxidative phosphorylation. These substances frequently serve as mediators between a plant and its surroundings and oversee energy transduction, color, signaling, defense, scent, and flavor. Some of the natural quinone components with antifungal, antibacterial, antioxidant, anti-cancer, anti-inflammatory, laxative, and anti-allergen properties have been employed in pharmacology to cause cytoprotection in humans [21-23a-b].

It is known that glycohybrids are an important class of molecules that exhibit diverse biological activities and are present as structural motifs in many natural products. Glycohybrid structures are formed by linking/connecting heterocyclic rings or hydrocarbon chains and carbohydrate moieties with biologically relevant molecules without changing their initial structure much. These molecules are known as glycohybrids [24a-b]. Linking or merging carbohydrates with bioactive molecules provides a viable source for chemical libraries in drug discovery and development [25]. The glycosylation of bioactive molecules of both synthetic and natural origin most often improves the pharmacological properties and ADMET parameters of the drug. Thus glycoconjugation has emerged as one of the most effective approaches for targeting cancerous cells by linking or merging the pharmacophoric moiety to the glycosyl/carbohydrate unit [25].

Glycohybrid molecules are used in the creation of pharmaceuticals due to their biological activity, high diversity, improved pharmacokinetic and pharmacodynamic properties [26, 27], molecular recognition, intracellular functions, enhanced bioavailability, high water solubility, and low toxicity [28, 29].

Numerous medicinal chemists worldwide have combined organic molecules quinone with carbohydrates, resulting in the production of novel glycohybrids (**D-I**), as shown in (Fig. 2), with varying structural and functional features [30, 31]. These innovative glycohybrids may exhibit enhanced biological activity or prove to be more efficient, safe, and affordable as potential pharmaceutical candidates. On the basis of these innovations, we have chosen to review and investigate the literature about the recently reported synthesis of quinone-based glycohybrids and their related biological activities. These recent literature reports covering the years 2017-2023 are presented here in this book chapter.

CHAPTER 6

Pharmacodynamics of Quinones and their Derivatives

Ganesh Sonawane^{1,*}, Shashikant Bhandari², Ritu Gilhotra³ and Ashutosh Kumar Dash⁴

¹ Divine College of Pharmacy, Satana, Nashik (Maharashtra) India

² AISSMS College of Pharmacy, Pune (Maharashtra) India

³ School of Pharmacy, Suresh Gyan Vihar University, Jaipur (Rajasthan) India

⁴ Senior Research Scientist (R&D), Drug Discovery Division, Macleod Pharmaceuticals Ltd, Mumbai, India

Abstract: Quinones and their derivatives are a diverse group of compounds with significant pharmacological potential rooted in their unique redox properties and ability to interact with various biomolecules. This chapter explores the pharmacodynamics of quinones, highlighting their mechanisms of action, including electron transfer, generation of reactive oxygen species (ROS), and interactions with DNA, proteins, and lipids. These mechanisms underpin their therapeutic applications in oncology, antibacterial and antifungal treatments, antiviral therapies, and other medical areas such as anti-inflammatory and neuroprotective interventions. Despite their promise, the development of quinone-based drugs is challenged by issues of stability, solubility, and toxicity. Advances in drug delivery systems, such as nanoparticles and liposomes, and the creation of novel quinone derivatives are critical to overcoming these obstacles. Moreover, the potential for personalized medicine, leveraging genetic profiling and biomarkers, represents a transformative approach to optimizing quinone therapies. The chapter also addresses the current regulatory and safety considerations in quinone drug development and highlights future research directions, including combination therapies and the use of artificial intelligence in drug discovery. Overall, while challenges remain, ongoing innovations and research efforts are poised to enhance the therapeutic efficacy and safety of quinone-based drugs, unlocking their full potential in modern medicine.

Keywords: Anticancer therapy, Drug delivery systems, Pharmacodynamics, Personalized medicine, Reactive oxygen species, Quinones.

* Corresponding author **Ganesh Sonawane**: Divine College of Pharmacy, Satana, Nashik (Maharashtra) India; E-mail: gbsonawane8@gmail.com

INTRODUCTION

Quinones are a class of organic compounds that are characterized by a fully conjugated cyclic dione structure. Structurally, quinones are derived from aromatic compounds like benzene, naphthalene, or anthracene, where two hydrogen atoms on the ring are replaced by oxygen atoms, creating a system of alternating double bonds. This conjugated system is responsible for the distinctive chemical properties and reactivity of quinones. The general formula for quinones can be represented as $C_6H_4O_2$ for benzoquinones, but this can vary based on the type and complexity of the parent aromatic system [1].

Quinones are known for their ability to participate in redox reactions, which is a key feature underlying their biological and pharmacological activities. The redox cycling of quinones involves the reversible reduction of quinones to hydroquinones (quinols), which can then be reoxidized back to quinones. This redox activity allows quinones to participate in various biochemical processes, including electron transport chains and redox signaling pathways.

The aromaticity of quinones also contributes to their chemical stability and reactivity. The delocalized π -electron system across the conjugated dione structure makes quinones relatively stable compounds yet reactive enough to interact with biological molecules and participate in electron transfer reactions.

Quinones are naturally occurring in many plants, fungi, and bacteria. They are often involved in pigmentation (*e.g.*, anthraquinones in madder root), defense mechanisms (*e.g.*, juglone in walnut trees), and cellular respiration (*e.g.*, ubiquinones in the mitochondrial electron transport chain).

In synthetic chemistry, quinones are typically produced through the oxidation of phenols or anilines. For example, the industrial production of benzoquinone often involves the oxidation of hydroquinone (1,4-dihydroxybenzene) using oxidizing agents like hydrogen peroxide or ferric chloride.

Quinones play crucial roles in various biological processes. One of the most well-known quinones, ubiquinone (coenzyme Q), is vital for the electron transport chain and ATP synthesis in mitochondria. Vitamin K, another important quinone, is essential for blood clotting and bone health. The redox properties of quinones enable them to function as electron carriers in biological systems.

Pharmacologically, quinones and their derivatives exhibit a range of activities, including anticancer, antimicrobial, anti-inflammatory, and antioxidant effects. Their ability to generate reactive oxygen species (ROS) through redox cycling

makes them useful in targeting cancer cells, which are often more susceptible to oxidative stress than normal cells [2, 3].

HISTORICAL BACKGROUND AND DISCOVERY

The discovery and study of quinones date back to the early 19th century. The first quinone, benzoquinone, was identified by Carl Wilhelm Scheele in 1786. However, it was not until the 1830s that Friedrich Wohler and Justus von Liebig elucidated the structure of quinones through their pioneering work in organic chemistry. Their research laid the foundation for understanding the chemical properties and reactivity of quinones, leading to the synthesis of numerous quinone derivatives and the exploration of their applications in various fields [4].

SIGNIFICANCE IN PHARMACOLOGY AND MEDICINE

Quinones and their derivatives have significant importance in pharmacology and medicine due to their wide range of biological activities. They exhibit various pharmacodynamic properties, including antimicrobial, anticancer, anti-inflammatory, and antioxidant effects. The biological activity of quinones is primarily attributed to their ability to undergo redox cycling, generating reactive oxygen species (ROS) that can induce oxidative stress and modulate cellular signaling pathways. This unique redox behavior makes quinones promising candidates for therapeutic applications in treating diseases such as cancer, cardiovascular disorders, and neurodegenerative conditions.

Furthermore, quinones are integral components of several vital biochemical processes. For instance, ubiquinone (coenzyme Q) plays a crucial role in the electron transport chain and ATP synthesis in cellular respiration. Similarly, vitamin K, a naphthoquinone derivative, is essential for blood coagulation and bone metabolism. The diverse pharmacological potential and therapeutic applications of quinones underscore their significance in modern medicine and ongoing biomedical research [5].

CHEMICAL STRUCTURE AND CLASSIFICATION

Basic Chemical Structure of Quinones

Quinones are characterized by a fully conjugated cyclic dione structure, typically involving an aromatic ring system where two carbonyl groups (C=O) replace two hydrogen atoms. This conjugation creates a system of alternating double bonds, giving quinones their distinctive reactivity and stability. The simplest quinone, benzoquinone, has the formula $C_6H_4O_2$, with the general structure for quinones

CHAPTER 7

Synthetic and Natural Quinones as Drug Candidates

Santosh Kumar Rath^{1,*} and Ashutosh Kumar Dash²

¹ School of Pharmaceuticals and Population Health Informatics, Faculty of Pharmacy, DIT University, Dehradun, Uttarakhand-248009, India

² Senior Research Scientist, Drug Discovery Division, Macleods Pharmaceuticals Ltd, Mumbai, India

Abstract: Quinones are a group of organic compounds that have a wide range of chemical properties and applications in various fields, such as pharmaceuticals, materials science, and organic synthesis. They are highly versatile and can be modified to produce derivatives with unique properties. This chapter presents a comprehensive and current overview of the chemistry and synthesis of quinones and their derivatives. It serves as an invaluable resource for chemists, researchers, and scientists who are interested in exploring the diverse aspects of this significant class of organic compounds.

Keywords: Mitochondrial activity, Natural naphthoquinones, Oxidative stress, Parkinson's disease, Ubiquinone.

INTRODUCTION

Quinones are a substantial class of naturally occurring intramolecular unsaturated cyclic diketone structures. Synthetically, they can be easily changed into similar structural scaffolds with a wide range of applications. It is well known that they play a crucial function in the biochemistry of living cells [1]. The main structural subtypes of natural quinones are benzoquinone, naphthoquinone, anthraquinone, and phenanthroquinone. Additionally, benzoquinone is further subdivided into o-benzoquinone and p-benzoquinone. However, because of the structural instability of o-benzoquinone, the majority of naturally occurring benzoquinones are derivatives of p-benzoquinone [2]. In addition to these physiological roles, quinones are formed by oxidative metabolism in various xenobiotics. Both a benzoquinoneimine metabolite generated by a cytochrome P450-dependent oxidase reaction and simple p-benzoquinone synthesized from the hydrolysis of

* Corresponding author Santosh Kumar Rath: School of Pharmaceuticals and Population Health Informatics, Faculty of Pharmacy, DIT University, Dehradun, Uttarakhand-248009, India; E-mail: ??

the benzoquinoneimine metabolite are responsible for the severe hepatotoxicity that can occur from an overdose of the analgetic paracetamol. Quinones are a unique class of naturally occurring secondary metabolites with anticancer characteristics. A common anthracycline antibiotic used in clinics to treat cancer is doxorubicin. Its 4-membered ring system comprises aminoglycoside, anthraquinone, and chromophore [3]. It is a first-line chemotherapy for breast cancer and is regarded as one of the most potent cancer medications on the market. Even though anthracycline antibiotics are often used in clinical settings, their usage is restricted due to their major adverse effects on healthy tissues and the emergence of drug resistance in cancer cells. The two most significant side effects of anthracycline chemotherapy are neurotoxicity and cardiotoxicity. As quinone derivatives have a structural resemblance to the anthracycline antibiotics that are already utilized in clinical practice, they may be extremely valuable in terms of their potential anticancer characteristics [4]. Additionally, as quinones are found in natural sources and are secondary metabolites, we should take into account the potential that their natural origin makes them relatively safe. For example, several species within several plant groups include structural similarities of naturally occurring quinones. These include the following: Liliaceae (species of Aloe, *etc.*), Hypericaceae (species of Hypericum, *etc.*), Polygonaceae (species of Rheum, Rumex, Polygonum, *etc.*), Rhamnaceae (species of Rhamnus, *etc.*), Rubiaceae (species of Rubia, Galium, *etc.*), Caesalpiniaceae (species of Cassia, *etc.*), Boraginaceae (Alkanna, Arnebia spec., *etc.*), and Juliandraceae (species of Juliens, *etc.*) [5]. Plants belonging to the families Polygonaceae, Rubiaceae, and Leguminosae have been identified as containing anthraquinones. Examples of these species include *Rheum palmatum* L., *Rubia cordifolia* L., *Polygoni multiflori*, *Polygonum cuspidatum*, and *Semen cassiae*. Furthermore, 200 of the approximately 700 distinct anthraquinone derivatives that have been identified are found in plants. The general classification of anthraquinones is into anthraquinone monomers, which are further separated into hydroxy anthraquinones, anthranones and anthranols, and bianthraquinones based on the mother nucleus' structure. Studies have shown that the anthracene nucleus serves as the primary structural component of many anticancer medications and that the activity of this nucleus is significantly influenced by a phenolic hydroxyl group. Anthraquinone monomers like emodin, aloe-emodin, rhein, chrysophanol, and physcion receive more attention. But, hypericin, a bianthraquinone variety, is also well-known for its beneficial pharmacological properties, which include anti-depressant, anti-cancer, and anti-viral properties [6].

NATURAL NAPHTHOQUINONES

Natural naphthoquinones, typically in the form of botanical extracts, have been connected to human existence since prehistoric times, far before they were isolated and identified in the present age. Natural quinones, a diverse class of organic compounds found in plants, fungi, and some marine organisms, have gained enormous attention as potential drug candidates due to their various biological activities. Quinones exhibit various pharmacological properties, including antioxidant, anticancer, antimicrobial, anti-inflammatory, and antiparasitic activities [7]. Furthermore, many quinones, such as the naphthoquinones Plumbagin from *Plumbago rosea* and Juglone from *Juglans nigra*, show growth-inhibitory effects on bacteria or fungus and are employed by plants as defensive compounds [8]. Naphthoquinones, such as Shikonin and Plumbagin, are the primary efficacious molecules in some commonly used medical herbals, particularly those that have antibacterial, insecticidal, antiphlogistic, and wound-healing properties [9]. Thymoquinone (2-isopropyl-5-methylbenzo-1,4-quinone) is a benzoquinone molecule widely distributed in the volatile oil portion of *Nigella sativa* seed [10]. Sargaquinoic acid, a hydroquinone acid isolated from *Sargassum siliquastrum*, has anti-inflammatory properties and impedes macrophages' ability to produce nitric oxide by interfering with LPS-induced signaling. Sargaquinoic acid prevented LPS-stimulated RAW264.7 macrophages from producing NO and from expressing the iNOS protein [11]. The adherence of monocytes to TNF- α -induced adhesion was inhibited by sargaquinoic acid. Additionally, by stopping the proteolytic degradation of inhibitor κ B- α , SQA prevented TNF- α -induced nuclear factor kappa B (NF- κ B) from translocating into the nucleus. Overall, SQA inhibits the NF- κ B pathway in HUVECs to prevent vascular inflammation caused by TNF- α [12]. Throughout their lengthy history of use, naphthoquinones have seen a change in use from their early uses as dyes and decorations to their current use as therapeutic compounds [13]. To date, much research has been done to clarify the pharmacological profile of synthetic and natural naphthoquinones. Naphthoquinones are derivatives of naphthalene with two carbonyl oxygen atoms in their structure. Although there are theoretically multiple naphthoquinone isoforms, 1,4-naphthoquinone is the most stable and well-reported one [14]. Many effective analogs, such as simple modified naphthoquinones like Lawsone, Shikonin, Juglone, Plumbagin, and Menadione, have been found based on this scaffold [15]. Additionally, the chemical space renders naphthoquinones stable ligands for a variety of pathologic targets, and in certain circumstances, naphthoquinones may be the preferred chemotype for the development of novel inhibitors.

CHAPTER 8

Understanding Quinones with Reference to Biochemistry

Adil Ali¹, Mohd Hasan Mujahid¹, Ankit Paul¹ and Tarun Kumar Upadhyay^{1,*}

¹ Department of Biotechnology, Parul Institute of Applied Sciences and Research and Development Cell, Parul University, Vadodara 391760, Gujarat-India

Abstract: Quinones are a highly flexible group of organic molecules that are naturally present in a diverse range of organisms, such as plants, algae, bacteria, and fungi. These chemicals are also artificially produced in laboratories for diverse purposes. Quinones possess a distinctive chemical structure that allows them to get involved in redox cycling. This means they can easily switch between oxidized and reduced states, a property that underlies many of their biological and pharmacological functions. They have a crucial function in the electron transport chain in both cellular respiration and photosynthesis. They help transmit electrons, which is essential for energy production in cells. Quinones play a crucial role in cellular signaling pathways and defense mechanisms against oxidative stress due to their capacity to perform redox reactions. Quinones possess a diverse array of pharmacological properties, making them highly valuable in the field of medicine. One of the most important uses of these is in the field of anticancer treatments. Quinone-derived chemicals serve as the foundation for some of the most extensive and potent categories of anticancer medications. Their cytotoxic qualities, which allow them to cause cell death in cancer cells, are utilized in treatments for different types of malignancies. Quinones can be classified into several broad categories, including anthraquinones, benzoquinones, phenanthraquinones, and naphthoquinones. These categories consist of a wide range of molecules that have unique chemical structures and biological properties. These classes constitute the fundamental components of numerous natural and synthetic products utilized across multiple industries.

Keywords: Anticancer properties, Novel drug, Oxidative stress, Pharmacological properties, Quinones, Redox reaction.

INTRODUCTION

Quinones are a group of chemical compounds representing a subclass of the quinoid family characterized by conjugated cyclic dione ($-\text{CH}=\text{CH}-$ groups converted

* Corresponding author Tarun Kumar Upadhyay: Department of Biotechnology, Parul Institute of Applied Sciences and Research and Development Cell, Parul University, Vadodara 391760, Gujarat-India; E-mail: tarun_bioinfo@yahoo.co.in

to $\rightarrow$ $-\text{C}(=\text{O})-$ groups) structures and consisting of quinonimines and quinomethanes (Fig. 1). This chemical group is mostly formed from reactive aromatic compounds like catechols or phenols. Their presence has been determined not only in natural products and biochemicals but also in pharmaceuticals and are requisite compounds having an extensive range of bioactivities [1, 2]. Since quinones represent the group of both naturally existing and synthetically prepared chemicals and are known to exhibit an extensive range of bioactivities such as antitumor, anti-bacterial, anti-cancer, and anticoagulant properties, they are widely applicable for medicinal and industrial purposes [3]. However, DNA is the main target of quinoid antitumor drugs, which contain the structure cyclohexadienedione. It is highly abundant and may be found in endogenous biochemicals, natural products, and environmental pollutants; these agents are alkylating and DNA intercalating agents. Secondly, quinoid chemicals have been demonstrated to target other cellular components, which include heat shock protein (HSP) 90 and telomerase [4, 5]. Examples of some compounds are aziridinyquinones (mitomycin C and Diaziridiny-benzoquinone) [6], naphthoquinones (vitamin K1, phyloquinone) [7], anthracyclines (Daunorubicin, Doxorubicin) [8], aminoquinones (such as streptonigrins), indolequinones (such as mitomycins), and certain vitamins that induce the production of hydrogen peroxide (H_2O_2) in tumor cells *via* redox cycling mechanism and autoxidation reaction to show anticancer activity [9] (Fig. 2). The isolation of quinone has been a research topic of global interest in recent times. ^{13}C nuclear magnetic resonance (NMR) spectroscopy is used in the analysis of the intersections of nature-derived quinones. Gathered data from past publications from 2000 to 2022 showed that out of 137 compounds, 70 were newly described [10]. From the biochemistry aspect, the quinones are important reduction-oxidation mediators for numerous electron-transfer chain (ETC) pathways in living systems and, as such, are crucial to countless enzymatic and physiological functional systems such as ubiquinone and plastoquinone and various naturally occurring quinones [11].

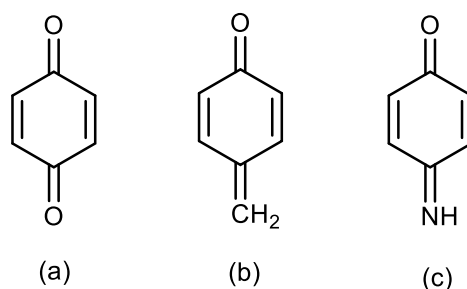


Fig. (1). Simplified structure of quinoids: a) *p*- Benzoquinone b) *p*- Benzoquinone methide c) *p*- Benzoquinone imine.

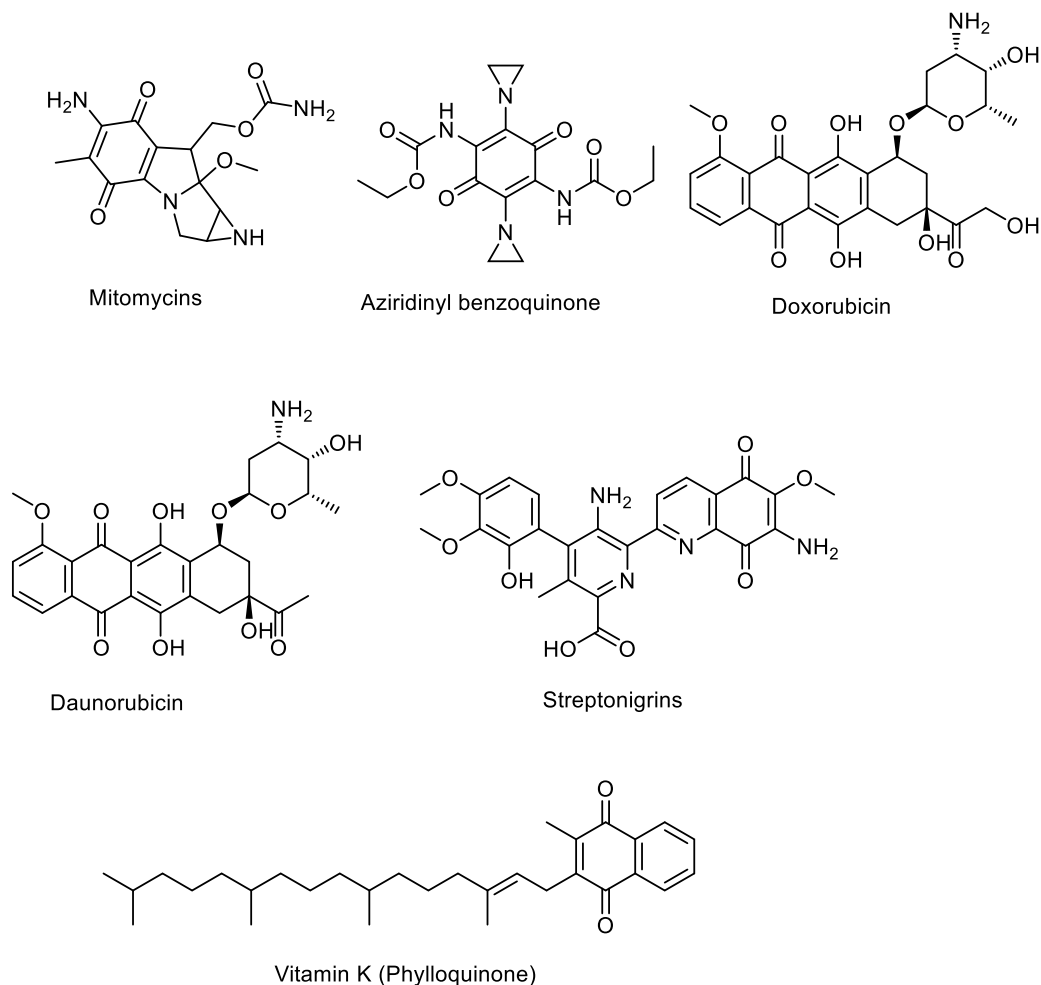


Fig. (2). Diagrammatical illustration of the 2D structure of the different compounds containing quinones moiety.

ISOLATION AND CHARACTERIZATION OF QUINONES

Natural quinones are derived from henna and juglone (walnuts) as well as from various sources such as microorganisms and animals. They are categorized based on the aromatic system in which they are found. The four primary groups of quinones are benzoquinones, naphthoquinones, anthraquinones, and phenanthraquinones, which encompass the majority of known compounds (Table 1). The subclassification of quinone is shown in Table 2 [10]. Quinone derivatives are often obtained through the process of maceration, percolation, or a mixture of both methods. Before applying these approaches, it is crucial to understand the characteristics of the dissolving solvents (polar or non-polar) to be utilized as they

CHAPTER 9

Quinone Compounds in Medicine: A Biological Perspective

Rajendra Dighe¹, Ashutosh Kumar Dash², Shashikant Bhandari³ and Ritu Gilhotra^{4,*}

¹ KBHSS Trust's, Institute of Pharmacy, Malegaon, Maharashtra, India

² Senior Research Scientist (R&D), Drug Discovery Division, Macleods Pharmaceuticals Ltd, India

³ AISSMS College of Pharmacy, Pune, Maharashtra, India

⁴ Gyan Vihar School of Pharmacy, Suresh Gyan Vihar University, Jaipur, Rajasthan, India

Abstract: Quinone compounds are versatile molecules with significant biological importance and have therapeutic potential in medicine. This chapter provides a comprehensive overview of quinones, beginning with their definition, historical background, and chemical structure. It explores their diverse roles in biological systems, including their involvement in cellular respiration, enzymatic reactions as co-factors, and their function as endogenous compounds. Mechanistically, quinones employ their effects through redox properties, electron transfer processes, and interactions with cellular components such as proteins, lipids, and DNA. Therapeutically, quinones are pragmatic for their anti-cancer, antimicrobial, anti-inflammatory, and antioxidant properties. Key drugs like doxorubicin and mitomycin C exemplify their efficacy in cancer treatment, while other quinones serve as antimicrobial agents against bacteria, fungi, and viruses. Challenges in drug development, including toxicity and stability issues, are addressed alongside strategies to mitigate these concerns. Case studies and clinical trial data underscore the clinical relevance of quinone-based therapies. Looking forward, future research opportunities include exploring novel quinone derivatives, integrating quinones in combination therapies, and advancing drug delivery systems to enhance their efficacy and safety profiles. The chapter concludes by emphasizing the significant role of quinone compounds in modern medicine and outlining potential breakthroughs that may further expand their therapeutic applications.

Keywords: Anthraquinones, Benzoquinones, Doxorubicin, Mitomycin, Naphthoquinones, Quinones, Reactive oxygen species, Vitamin K, Ubiquinone.

* Corresponding author Ritu Gilhotra: Gyan Vihar School of Pharmacy, Suresh Gyan Vihar University, Jaipur, Rajasthan, India; E-mail: drritugilhotra@gmail.com

Ashutosh Kumar Dash & Deepak Kumar (Eds.)
All rights reserved-© 2025 Bentham Science Publishers

INTRODUCTION

Quinones are a class of organic compounds characterized by a fully conjugated cyclic di-one structure. The most common quinones include benzoquinones, naphthoquinones, and anthraquinones [1]. Quinones are derived from aromatic compounds through the oxidation of hydroquinones. Their chemical structure typically includes a six-membered aromatic ring with two ketone substitutions, leading to their highly reactive nature due to the presence of electron-deficient carbonyl groups [2].

Quinones possess a basic structure of $C_6H_4O_2$ in the case of benzoquinones, extending to more complex forms such as naphthoquinones ($C_{10}H_6O_2$) and anthraquinones ($C_{14}H_8O_2$). The electron-deficient nature of the carbonyl groups makes quinones highly reactive and capable of participating in various redox reactions [3]. Quinones are typically yellow to red crystalline substances, exhibiting a distinctive coloration due to their conjugated system [4]. They have relatively low melting points and are soluble in organic solvents but exhibit limited solubility in water [5].

Quinones readily undergo reversible redox reactions, cycling between quinone and hydroquinone forms. This redox capability underpins many of their biological activities, including roles in electron transport and enzymatic reactions [6]. The redox properties are influenced by substituents on the aromatic ring, which can either donate or withdraw electrons, thus modifying the quinone's reactivity [7].

Quinones are ubiquitous in nature, playing vital roles in biological processes. For instance, ubiquinones (coenzyme Q) are essential for cellular respiration in the mitochondrial electron transport chain. They act as electron carriers and are involved in the synthesis of ATP, showcasing their importance in energy metabolism [8].

Naturally occurring quinones are found in a variety of plants, fungi, and bacteria. They are involved in pigmentation, such as in the case of lawsone (henna) and juglone (black walnut). Synthetically, quinones can be produced through various chemical reactions, including the oxidation of aromatic precursors and the cyclization of appropriate intermediates. The reactivity of quinones makes them suitable for a variety of applications, including medicinal chemistry. Their derivatives are used in anti-cancer, anti-microbial, and anti-inflammatory drugs due to their ability to generate reactive oxygen species and interact with biological macromolecules [9].

HISTORICAL BACKGROUND AND DISCOVERY IN MEDICINE

Early uses and Discovery

The medicinal use of quinone compounds dates back to ancient times, even before their chemical nature was understood. Natural quinones, especially those found in plants, have been used in traditional medicine for their therapeutic properties. One of the earliest known uses of a quinone compound is henna, derived from the plant *Lawsonia inermis*, which contains lawsone, a naphthoquinone. Henna has been used for millennia for its dyeing properties and potential medicinal benefits, including antimicrobial and anti-inflammatory effects [10].

19th Century: Isolation and Chemical Characterization

The 19th century marked significant advancements in the chemical isolation and characterization of quinones. In 1838, Pierre Joseph Pelletier and Joseph Bienaimé Caventou isolated the first quinone, quinone itself (benzoquinone), from the oxidation of quinic acid. This discovery laid the groundwork for understanding the chemical structure and reactivity of quinones.

Following this, in the late 1800s, notable chemists such as Friedrich Wöhler and August Kekulé contributed to the elucidation of the structures of various quinones. Wöhler, known for his synthesis of urea, also worked on the synthesis and study of benzoquinone. Kekulé's structural theories further advanced the understanding of aromatic compounds, including quinones [10].

20th Century: Biomedical Discoveries

The 20th century saw significant breakthroughs in the biological and medicinal applications of quinones. In the 1930s, research into the role of quinones in cellular respiration led to the discovery of ubiquinone (coenzyme Q10) by Frederick L. Crane and colleagues in 1957. Ubiquinone's crucial role in the mitochondrial electron transport chain and ATP synthesis underscored the biological importance of quinones [11].

Simultaneously, the anti-cancer properties of quinone compounds began to be explored. The anthracycline antibiotic doxorubicin, derived from the bacterium *Streptomyces peucetius*, was discovered in the 1960s and became a cornerstone in chemotherapy for various cancers. Its mechanism, involving DNA intercalation and the generation of reactive oxygen species, highlighted the potential of quinones in cancer treatment [12].

CHAPTER 10

Recent Study on Quinone Derivatives and their Applications

Suryakant R. Rode¹ and Ashutosh Kumar Dash^{2,*}

¹ *Jai Research Foundation Valvada, Valsad, Gujrat, India*

² *Senior Research Scientist (R&D), Drug Discovery Division, Macleods Pharmaceutical Ltd, Mumbai, India*

Abstract: Quinone and its derivatives have manifold applications in pharmaceutical industries. In this chapter, we look over the current practices of quinones and their derivatives in several fields. Recent studies have found that quinone-enhanced humification in food waste composting is a strategy for hazard mitigation and nitrogen retention. Quinone derivatives such as diazanthraquinone dimers have been demonstrated as high-capacity organic cathode materials for rechargeable lithium batteries. Their preparation and advantage over conventional batteries have been explained. Quinone-chlorophyll conjugation synthesized by the Diels-alder approach as conformers, called atropisomers, is a recent invention. Currently, in the field of pharmacological practices, quinone and its class of molecules have demonstrated a wide range of therapeutic properties, such as anticancer, anti-inflammatory, and antibiotic.

Keywords: Anticancer agents, Benzoquinone anthraquinone, Diel's alder reaction, Lithium-ion batteries, Naphthoquinone, Pictet Spengler annulation, Quinone.

INTRODUCTION

Quinones are electron carriers that play a role in photosynthesis. As vitamins, they represent a class of molecules preventing and treating several illnesses such as osteoporosis, cardiovascular diseases, cancer [1, 5], bacterial infection, *etc.* They are used in Li-ion batteries [3] and food waste composting [2]. Quinone and chlorin are conjugated *via* the Diels-Alder reaction; the resulting compound can exhibit unique electronic properties due to the new conjugated π -system [4]. One fascinating study observed the synthesis of bis(arylamino) pentaptycenes using pentaptycene quinone in a one-pot process [6]. Quinones exist in nature in many forms, such as benzoquinones, naphthoquinones, anthraquinones, and polycyclic

* Corresponding author Ashutosh Kumar Dash: Jai Research Foundation Valvada, Valsad, Gujrat, India; E-mail: ??

quinones [7 - 9]. For example, vitamin K (phylloquinone) include naphthoquinones, emodin, physcion, cascarin, catenarin, and rhein. Anthraquinones and benzoquinones are present in nature and are named carthamins. In this article, we have discussed about recent novelty of work on quinone and its derivative.

CLASSIFICATION OF QUINONES

Benzoquinones

Benzoquinones (Fig. 1), such as lawsone, plumbagin, and 1,4-benzoquinone (menadione), exhibit various biological activities, including antioxidant, antibacterial, and anticancer effects. Pharmacological targets and pathways include NAD(P)H: quinone oxidoreductase 1 (NQO1), topoisomerases, and the proteasome. Key pathways involve reactive oxygen species (ROS) generation, DNA damage, and inhibition of the proteasome [9, 10].

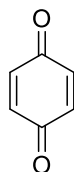


Fig. (1). Structure of benzoquinone.

Naphthoquinones

Naphthoquinones (Fig. 2) have two carbonyl groups within their naphthalene ring structure. Lawsone, a naphthoquinone, is derived from the henna plant and is a ideal example in this category. The cytotoxic and antitumor properties of naphthoquinones are well-documented, and their potential as anticancer agents has been extensively researched. Pharmacological targets and pathways for naphthoquinones include thioredoxin reductase, topoisomerases, and the mitochondrial electron transport chain. Key biological pathways involve redox regulation, DNA damage, and mitochondrial dysfunction [9, 10].

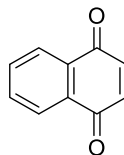


Fig. (2). Structure of naphthoquinones.

ANTHRAQUINONES

The nucleus consists of tricyclic anthracenes featuring two carbonyl groups, which can be readily sourced from plants and fungi. Notable examples include emodin, aloe-emodin, and rhein. Anthraquinones (Fig. 3) are known for their diverse biological activities, including anti-inflammatory, anticancer, and antibacterial properties. Mode of action as targets includes protein kinase C (PKC), NF- κ B, and topoisomerases in cancer and other illnesses. Associated biological pathways encompass the modulation of protein kinases, inflammatory processes, and responses to DNA damage [9 - 11].

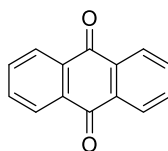


Fig. (3). Structure of anthraquinone.

Heteroquinones

Heteroquinones (Fig. 4) comprise one or more heteroatoms, such as oxygen, sulfur, or nitrogen, within their ring structure. Examples include menadione bisulfite, a water-soluble form of menadione, and plumbagin, both of which are naturally occurring compounds featuring a quinone-oxygen bridge. These compounds often possess unique chemical and biological properties that make them promising candidates for drug development [9, 10, 12].

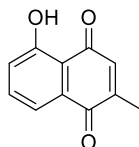


Fig. (4). Structure of heteroquinone.

Pharmacological targets include topoisomerases and DNA methyltransferases, along with reactive oxygen species (ROS) generation. The associated biological pathways involve DNA damage, epigenetic modulation, and oxidative stress responses.

These quinone derivatives have recently been used for emerging sustainable and highly efficient batteries, surpassing traditional lithium-ion battery technology. The development of diazaanthraquinone dimers has led to high-capacity organic cathode materials for rechargeable lithium batteries. 2,2'-bi(1,8-diazaanthraquinone) (Li8-BDAAQ) is a recent example. The unique structure of Li8-BDAAQ, with its multiple redox-active sites and the ability to coordinate with lithium ions, makes it a promising candidate for high-performance battery materials. The general process of formulating has been described as follows [3].

SUBJECT INDEX

A

- Absorbance ratio 59
- Acetamide 10
- Acetaminophen 143
- Acetic acid 27, 56
- Acetonitrile 96, 108, 243
- Acetylcholinesterase 9, 10, 41, 183
- Acetylshikonin 184
- Acetylthioglucosides 106
- Acute myeloid leukemia 161
- Adipose-derived stem cells 157
- Agents 10, 24, 25, 66, 123, 131, 142, 143, 147, 163, 200, 220, 222, 236
 - anti-inflammatory 66, 236
 - anti-protozoal 163
 - antiradical 123
 - bacteriostatic 10
 - cardioprotective 143, 220
 - chemotherapeutic 147, 222
 - multifunctional 222
 - oxidizing 24, 25, 131, 200
 - protective 142
- Aggregation-induced emission (AIE) 37
- Aging 160
 - process 160
 - tissues 160
- Aldehyde 118, 244
- Aldose reductase 6
- Allomicrophyllone 182
- Aloesaponarin 178, 183
- Amino anthraquinone derivatives 36
- Aminoglycoside 152
- Aminonaphthoquinones 40
- Aminoquinones 30, 168
- Analogues 41, 153, 186
 - effective 153
 - novel 41, 186
 - synthesized 41
- Anthracenecarboxylic acid 184
- Anthraquinone 9, 88, 152, 171, 172, 174, 182, 234
 - chemicals 172
 - conjugate 234
 - derivatives 9, 182, 234
 - dye 174
 - glycosides 171
 - moiety 88
 - monomers 152
- Antifungal 33, 40, 139, 143, 175, 180
 - activities 139, 143
 - agents 175
 - properties 33, 40, 180
- Antimicrobial 10, 11, 12, 68, 69, 70, 71, 75, 149, 155, 156, 195, 212, 218, 243
 - activities 68, 70, 75, 155, 156, 212, 243
 - agents 195, 243
 - applications 243
 - chemotherapy 10
 - drug 12
 - effects 68, 70, 149
 - medicines 10
 - properties 11, 69, 70, 71, 212
 - prophylaxis 10
 - resistance 11
 - therapies 218
- Antimycotic 182
- Antinociceptive effects 156
- Antioncogenic effects 174
- Antioxidant 4, 18, 65, 66, 72, 75, 76, 136, 141, 160, 163, 199, 210, 213, 218, 222, 223
 - activity 4, 72, 76, 160
 - agents 163
 - co-therapy 218
 - defense 199
 - enzymes 66, 213
 - properties 4, 18, 65, 72, 75, 76, 141, 210, 213, 222, 223
 - proteins 136
- Antiparasitic 2, 162
- Antiphlogistic 153, 162
- Apoptosis 41, 180, 238
 - elicit 180

Subject Index

promoting 238
tumor cell 41
Arterial calcification 54
Ascorbic acid 5, 115
Ayurvedic 68, 71, 72, 73
formulations 73
medicine 68, 71, 72, 73

B

Bacillus subtilis 69, 92
Betulinic acid 139, 145

C

Calvin cycle 200
Candida albicans 69, 143
Carbonyl 20, 52, 87, 88, 111, 132, 134, 171,
172, 174, 201, 202, 203, 229, 230
bonds 52
groups 20, 87, 88, 132, 134, 171, 172, 174,
201, 202, 203, 229, 230
oxygen 111
Cardiac myocytes 142
Cardiomyopathy 142, 217
Chemistry 78, 131, 132, 154, 173, 177, 181,
196, 198, 240, 243, 245
clinical 78
medicinal 154, 173, 181, 196, 243, 245
organic 132, 177
polymer 240
supramolecular 240
synthetic 131, 198
Chirita eburnean 4
Chromatography 57, 58, 170, 234, 235
flash 234
high-performance liquid 57, 58, 235
high-pressure liquid 170
preparatory thin-layer 170
ultra-high pressure liquid 170
Chromophore 152
Cladosporium cucumerinum 69

Quinones and their Derivatives 249

Collision-induced dissociation (CID) 59
Cyanobacteria 180
Cyanophthalide 116
Cynoglossum zeylanicum 183

D

Damage 141, 144, 159, 237
kidney 141, 144
membrane 237
muscle 159
Degradation 153, 222, 245
pollutant 245
premature 222
proteolytic 153
Design 215, 216, 218, 223
prodrug 216, 218
strategic 215, 223
Dextrazoxane 143
Diarylmethyl thioglycoside 102
Diazaanthraquinone 231
Disorders 1, 3, 6, 68, 75, 80, 132, 154, 157,
158, 159, 162, 198, 213, 219
bleeding 219
cardiovascular 132
digestive 68
gastrointestinal 75
infectious 1
metabolic 6, 157
mitochondrial 154, 158, 159, 162
neurodegenerative 3, 80, 198, 213
Doses 78, 80, 141, 142, 144, 148, 158, 218
daily 78, 158
high 80, 141, 144
lower 141, 148
optimal 218
repeated 218
tolerated 144
total 142

E

Electrochemistry 177
Electrocyclization 123
Electron transport 52, 54, 131, 132, 136, 137, 140, 154, 158, 162, 167, 200, 205, 206, 209
 chains 131, 132, 136, 137, 140, 154, 158, 162, 167, 200, 205, 206, 209
 pathways 54
 process 52
Electrophiles 2, 205
Electrophilic aromatic substitution 244
Electrostatics 176
Endogenous quinones 210
Enzymatic 70, 140, 172, 199, 210
 activity 70, 140, 210
 cofactors 199
 dimerization 172
Escherichia coli 69
Ethyl 117, 170
 acetate 170
 alcohol 170
 vinyl ether 117

F

Fenton reaction 65
Fibril formation 78
Fibromyalgia 159
Flacourtia Jangomas 68
Furano 171
 anthraquinones 171
 naphthoquinones 171

G

Gas spectrometry 59
Glucuronic acid 138
Glutathione S-transferase (GST) 236
Glycohybrid 89
 molecules 89

structures 89

H

Halogenoquinones 103
Hammett equation concept 3
Hauser annulation 116, 118
Heat shock protein (HSP) 13, 168
Helicobacter pylori 178
Human fibroblast-like synoviocytes 72
Hydrobromic acid 93

I

Inducible nitric oxide synthase (iNOS) 8, 155
Interactions 87, 148, 178, 185, 208
 biological 148
 interkingdom 178
 non-covalent 185, 208
 protein-carbohydrate 87

J

Juglans 8, 68, 153, 181
 mandshurica 8
 nigra 68, 153, 181
Juglone 103
 compounds 103
 derivatives 103

K

Kaposi's sarcoma 161
Kermesic acid 33
Kniphofia 183

L

Lactate dehydrogenase 159
Lapachol 88, 94, 140, 155, 156, 213
Lappaconitine 162

Subject Index

Lawsonia inermis 68
Lewis acid catalysts 26
Lipophilic quinones 137
Lithospermum erythrorhizon 77, 155
Long-term potentiation (LTP) 158

M

Malbranchea cinnamomea 3
Materials 4, 20, 24, 181, 232
 cathode 232
 functional 20
 inorganic 232
 natural 4
 organic 4, 232
 polymer 24
 raw 181
 traditional cathode 232
Mendoncia cowanii 69
Methylobacterium extorquens 179
Michael addition reactions 2
Mitochondrial 41, 94, 131, 134, 135, 136, 141, 144, 155, 159, 179, 196, 197, 199, 205, 207, 214, 216, 217, 229
 dysfunction 141, 144, 159, 217, 229
 electron transport chain 131, 134, 135, 196, 197, 199, 205, 207, 214, 216, 217
 functionality 179
 integrity 159
 membrane 136, 155, 216
 proteins 159
 stress 41
 transmembrane 94
Mucosal lining 74
Multitarget-directed ligand (MTDL) 41

N

Naphthacenequinone 34
Naphthalene 52, 71, 131, 133, 153, 173, 201, 202, 229

Quinones and their Derivatives 251

Naphthoquinone 20, 37, 88, 137, 156, 202, 229, 234
 conjugate 234
 derivatives 37, 137
 glycosides 88
 molecule 156
 structure 20, 88, 202, 229
Nerve growth factors (NGF) 78
Nucleophilic 2, 23, 112, 205
 additions 23, 112
 residues 2
 sites 205
Nutraceutical 64, 65, 66, 75
 ethics 64
 industry 65
 products 65, 66, 75
 use 64

O

Obenzoquinone 151
One-pot 181, 123, 228, 240
 experiment 181
 iminium-ion 123
 process 228
 synthesis procedure 240
Ophthalmic surgery 219
Oral 6, 160
 glucose tolerance test 6
 supplementation 160
Organic compounds 3, 233
 complex 233
 cyclic 3
 degradable 233
Organic 53, 55, 196, 233, 240, 242
 field-effect transistors (OFETs) 242
 light-emitting diodes (OLEDs) 242
 oxidations 53
 quinones 55
 solution 240
 solvents 196
 waste 233

Ortho- 4, 133, 172, 200, 201
 benzoquinone 4, 133, 172, 200, 201
 naphthoquinones 133, 201
Oxidation 112, 118, 181
 airborne 118
 allylic 112
 palladium-catalyzed 181

P

Paranaphthoquinone 133
Parkinson's disease 151, 157, 222
Pathways 41, 64, 65, 66, 137, 139, 156, 172,
 177, 185, 199, 201, 206, 208
 biochemical 64, 156, 201
 cysteine protease 41
 detoxification 199
 enzymatic 206, 208
 inflammatory 66
 metabolic 137, 185, 206
 mitochondrial 139
 modulating 65
 oxidizing 177
 polyketide 172
Peri Tox test 95
Peripheral neuropathy 142
Pharmacophoric 13, 89
 abilities 13
 moiety 89
Phenanthrafuranoquinones 29
Phenanthraquinones 167, 169, 171, 175, 176,
 185
Photovoltaics 20
Phylloquinone 52, 54, 58, 79, 168, 172, 173,
 180, 229
Pictet Spengler annulation 228
Piperidinoquinones 31
Plasmodium 156, 198
 falciparum 198
 lapohuræ 156
Plumbago 68, 72, 73, 74, 77, 153, 154, 182

rosea 153, 182
 zeylanica 68, 72, 73, 74, 77, 154, 182
Polygonum cuspidatum 152, 154
Propylphosphonic anhydride 122
Protein kinase C (PKC) 230
Pseudomonas aeruginosa 178
Pseudomonas quinolone signal (PQS) 178

Q

Quenching 234
Quercetin 101
Quinhydrone 22
Quinic acid 197
Quinone 1, 2, 3, 20, 21, 35, 53, 67, 68, 71, 87,
 88, 130, 132, 136, 146, 147, 149, 164, 174,
 195, 215, 221, 222, 239
 derivatives 1, 35, 130, 146, 149, 164, 195,
 221, 222
 dyes 87
 framework 21
 function 136
 scaffold 2, 67, 68
 stability 239
 structures 3, 20, 21, 53, 71, 88, 132, 147,
 174, 215
 synthesis 20, 88

R

Reaction 55, 57, 90, 177, 240, 243
 mixture 90, 240, 243
 processes 177
 progress 243
 time 57
 vessel 55, 90, 243
Renewable resources 232
Rheum 6, 68, 77, 152, 154
 emodi 6
 officinale 68, 77
 palmatum 68, 152, 154
 undulatum 6

Subject Index

Rubia 152, 179
 cordifolia 152
 tinctorum 179

S

Salvia miltiorrhiza 213
Saponification 114
Sargaquinoic acid 153, 162
Sargassum siliquastrum 153
Schiff bases 36, 119, 244
Skin 68, 70, 75, 80, 141, 142, 160
 care 160
 diseases 68, 75
 infections 70
 irritation 141
 rashes 80, 142
Species 53, 65, 137, 139
 aerobic 53
 fungal 139
 reactive 65, 137
Staphylococcus aureus 11, 69, 143
Staudinger reaction 96
Stereochemistry 3
Stereoisomers 234
Streptomyces 161, 179, 180
 caespitosus 180
 coeruleorubidus 161
 hygroscopicus 179
 peucetius 161, 180

T

Toll-like receptors (TLRs) 7
Trastuzumab 220
Trihydroxy naphthoquinones 171
Trypanosoma brucei 178

V

Vaginal cytology 78
Vatiquinone 82

Quinones and their Derivatives 253

Vinorelbine tartrate 121
Viral 140, 143, 212
 infections 140
 proteases 140
 replication 140, 143, 212
Vitis coignetiae 181

W

Weighted mean differences (WMD) 157
Weitz's aminium salt 23
Western blotting 78
Wolff-Kishner reduction 231

Z

Zemplén conditions 122



Ashutosh Kumar Dash

Dr. Ashutosh Kumar Dash is Group Leader cum Senior Research Scientist at MacLeods Pharmaceuticals Ltd (Drug Discovery Division) since 2023. He was Group Leader at Dev Synthesis India Pvt. Ltd (2021–2023), Associate Professor at GH Rasoni University, and Assistant Professor at four Indian universities. He earned his PhD and postdoc at CSIR-IIIM, Jammu. With 14 years' experience in research and academia, his expertise includes Medicinal, Organic, and Pharmaceutical Chemistry. He has worked on green chemistry, synthesis of APIs, drug metabolites, and natural products. His research spans Drug Discovery, DOS, semi-synthetic modifications, and target-based studies for cancer, diabetes, and inflammation. He has 39 peer-reviewed publications, book chapters with Springer, RSC, Elsevier, and completed 4 major projects (BIRAC, ICMR, etc.). A member of ACS and Bentham ambassador, he serves on six editorial boards. He has mentored 6 awarded PhDs, 5 current PhDs, 14 M.Pharm, and 32 B.Pharm students. He is also an editor and contributor to this book.



Deepak Kumar

Dr. Deepak Kumar is Professor in the Department of Pharmaceutical Chemistry, School of Pharmaceutical Sciences. He earned his PhD from South Korea under the prestigious Brain Korea 21Plus fellowship and completed his M Pharm from Sikkim Central University. He has been invited as Chairperson, keynote, and session speaker at reputed national and international conferences. His awards include the High Impact Factor Research Award 2022 by the Governor of Himachal Pradesh, Excellence Research Award 2022, International Scientist Awards 2021, Young Scientist Award 2020, Innovative Research Award 2019, and Young Investigator Award 2016. He received the BK21 Plus Travel Grant for the Gordon Research Conference. He serves as reviewer for scientific journals, consultant to industries, and committee member in various universities. Dr. Kumar is an active member of the American Chemical Society, Association of Pharmacy Profession, and Chemical and Pharmaceutical Societies of India and South Korea. His research spans Medicinal Chemistry, Drug Delivery, Nanomedicine, and Chemical Biology.