Mohd Ashraf Rather · Adnan Amin ·
Younis Ahmad Hajam · Ankur Jamwal ·
Irfan Ahmad *Editors*

Xenobiotics in Aquatic Animals

Reproductive and Developmental Impacts

Springer

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Dedicated
To
The Earth, the lovely planet that we know of

Foreword 1

Xenobiotic pollution of the environment has become a serious problem on a global front. Due to high toxicity, protracted persistence, and restricted biodegradability, many xenobiotic chemicals have a negative influence on the environment, especially the aquatic environment. Different types of xenobiotics, which are credited with saving millions of lives in recent decades, have emerged as a new category of an environmental hazard. These substances can affect the natural flora and fauna in ways that are both acute and chronic. These pollutants can be found in a variety of water sources, including groundwater, surface waters, seawater, wastewater treatment plant influents and effluents, soils, and sludges.

Looking into the threat posed by hazardous chemicals from the perspective of species vulnerability, researchers have the opportunity to take steps to reduce those risks, such as managing habitat, the ocean, freshwater, and fisheries. To manage the vulnerability of aquatic ecosystems to toxic chemicals, more research is needed to develop biomarkers of vulnerability, identify the most vulnerable life stages and populations of the aquatic ecosystem, and comprehend the linkage between pathogens, hazardous chemicals, nutritional status, and environmental changes on a global scale.

The exposure of aquatic animals to xenobiotics and the demand for chemical therapeutic agents for aquatic animals will both rise as the aquaculture sector is in an escalating stage. The book *Xenobiotics in Aquatic Animals: Reproductive and Developmental Impacts* has been the outcome of the contributions made by different national and international experts working on xenobiotics in aquatic systems. I sincerely believe the book would greatly help towards enhancing the understanding of readers including scientists, teachers, students, researchers, policymakers, and all those who are interested in working in this particular area.

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General (Fisheries Science), ICAR,
New Delhi, India
J. K. Jena

Foreword 2

The idea that environmental risks are to blame for the reproductive and developmental problems aquatic animals experience has been brought to light most convincingly by several studies undertaken over the last few decades. Recent years have seen a significant increase in the number of chemicals discharged into our environment, especially aquatic ecosystems. Each year, thousands of tons of synthetic chemical substances are generated; these compounds have already been approved for use in industry and agriculture. Their use has been continuing unabated, despite increasing awareness of their longstanding impacts.

In order to identify, regulate, and potentially intervene in xenobiotic exposure and its impacts on ecosystems and people, a significant amount of research has been conducted recently to understand better how xenobiotics behave in aquatic organisms. As a resource for human needs, the ecosystem's general health and safety should be our concern in this predicament.

In this context, I am happy to see this compilation of xenobiotic stressors on aquatic ecosystems that significantly impact aquatic organisms and dependent communities. This book, titled *Xenobiotics in Aquatic Animals: Reproductive and Developmental Impacts*, focuses on several significant and recently updated aspects of various xenobiotics entering aquatic ecosystems, including their effects on reproductive physiology, developmental biology, breeding biology, hormonal imbalance, aquatic ecology, and pollution to aquatic ecosystems. Readers, including scientists, teachers, students, researchers, policymakers, or anyone interested in this field, can benefit from the book's unique mix of various stressors on aquatic organisms, under a single cover.

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Aquaculture Program, Asian Institute of Technology (AIT), Bangkok, Thailand

Krishna R. Salin

Preface

India has an exclusive economic zone that is 2.02 million square kilometres in size, a continental shelf that is 0.506 million square kilometres, and a coastline that is around 8129 km long. In 2019–20, India produced 14.16 million metric tonnes of fish, keeping its position as the second largest fish producer in the world. Fish production has increased by an average of 7.53% annually over the last 5 years, demonstrating the industry's phenomenal expansion. There are more native freshwater fish species in India than in any other nation in continental Asia, making it one of the world's key hotspots for biodiversity. The cold-water fisheries support 258 species of freshwater fish from 21 families and 76 genera. Snow-trout, brown trout, Chinese carps, and rainbow trout are among the 258 cold-water fish species both native and foreign reported from Indian uplands that are commercially significant. Following shrimp, which makes up 15% of all trade in terms of value, trout and salmon are the second most valuable fish species traded worldwide. More than 6% (five million tonnes) of the world's aquaculture production is made up of trout and salmon (SOFIA FAO 2020).

The entire world is searching for a sustainable source of food security. Aquaculture is steadfastly upholding expectations. The dominance of fish and fisheries products in terms of growth rate and future potential to provide nutritional security is evident from the food production sector scenario of today. According to "The State of World Fisheries and Aquaculture," aquaculture generated almost 46% of the total 178.5 million tonnes of fish produced in 2020. Around 88% of the total fish production was used for direct human consumption (SOFIA 2020). India's aquaculture industry has grown significantly over the past 10 years, and the country is now prepared to expand by embracing cutting-edge aquaculture technologies and species diversification to make the most of its vast potential water resources.

Many efforts have been made recently to comprehend how xenobiotics operate in aquatic species in order to recognise, control, and maybe intervene in xenobiotic exposure and its effects on ecosystems and people. In this case, our primary concerns should be the ecosystem's overall health and safety as well as its capacity to meet human requirements.

The focus of this book, ***Reproductive and Developmental Impact of Xenobiotics in Aquatic Animals***, is on a number of significant and recently updated aspects of various xenobiotics entering aquatic ecosystems, such as their effects on reproductive physiology, developmental biology, breeding biology, hormonal imbalance, aquatic ecology, and pollution to aquatic ecosystems.

The unique grouping of numerous stressors on aquatic organisms under a single title has benefits for readers, including scientists, teachers, students, and researchers.

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We greatly appreciate the support of our students, co-workers, and family members.

We will also take this opportunity to express our sincere gratitude to Springer Publishing Company for publishing this work. Thank a lot.

Last but not least, we would like to bow down before the Almighty, who has given us the bravery, passion, and strength to finish this effort.

Dated: 30/12/2022.

Mohd Ashraf Rather
Adnan Amin
Younis Ahmad Hajam
Ankur Jamwal
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Contents

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Ankur Jamwal is an assistant professor at Azim Premji University, Bengaluru, India. Dr. Jamwal has over a decade of experience as an aquatic biologist and ecotoxicologist and has published over twenty research articles in international journals of repute. In addition to studying the effects of stress on the physiology of aquatic animals, Dr. Jamwal is also interested in the risk assessment of consumption of food cultivated using water that may be contaminated with toxic elements and compounds. He applies the concepts of aquatic physiology to developing sustainable aquaculture practices. Dr. Jamwal has received multiple awards, including the Best Fisheries Graduate of India—2010 and ICAR International Fellow. He is a passionate speaker and loves to spread awareness on climate change and the conservation of aquatic ecosystems.

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Abbreviations

2-NA	2-Naphthylamine
4-ABP	4-Aminobiphenyl
AhR	Aryl hydrocarbon receptor
ALL	Acute lymphocytic leukaemia
ANLL	Acute nonlymphocytic leukaemia
ASCR	Association of Swiss Cancer Registries
ASL	Angiosarcoma of the liver
ATSDR	Agency for Toxic Substances and Disease Registry
b.p.	Boiling point
BCME	Bis(chloromethyl)ether
BP	Benzo pyrene
BSF	Benzene-soluble fraction
BSM	Benzene-soluble materials
BW	Body weight
CA	Chromosomal aberration
CAS	Chemical Abstracts Service (of the American Chemical Society)
CI	Confidence interval
CMME	Chloromethyl methyl ether
CNS	Central nervous system
CPTV	Coal-tar pitch volatiles
CSF	Cyclohexane-soluble fraction
CYP	Cytochrome P450
DCM	Dichloromethane
DEHP	Diethylhexylphthalate
DHBMA	1,2-Dihydroxybutyl mercapturic acid
DLC	Dioxin-like compound
DMSO	Dimethyl sulfoxide
EH	Epoxide hydrolase
EPA	Environmental Protection Agency

EU	European Union
FISH	Fluorescence in situ hybridization
GST	Glutathione S-transferase
HCC	Hepatocellular carcinoma
HPRT	Hypoxanthine-guanine phosphoribosyltransferase
HRR	Hazard rate ratio
IH	Industrial hygiene
IRR	Incidence rate ratio
ISCO	International Standard Classification of Occupations
ISIC	International Standard Industrial Classification
MBS	Morpholinomercaptobenzothiazole
MBT	2-Mercaptobenzothiazole
MDS	Myelodysplastic syndromes
mEH	Microsomal epoxide hydrolase
MGP	Manufactured gas plant residues
MHBMA	Monohydroxy-3-butenyl mercapturic acid
MHBVal	N-(2-hydroxy-3-butenyl)valine
MN	Micro nucleus
MOCA	4,4′-Methylene-bis-(2-chloroaniline)
MPD	Myeloproliferative disorder
MT	Metallothionein
NAT	N-acetyltransferase
NDBA	N-nitrosodibutylamine
NDEA	N-nitrosodiethylamine
NDMA	N-nitrosodimethylamine
NDPA	N-nitrosodiphenylamine
NG	Not given
NIOSH	National Institute for Occupational Safety and Health (USA)
NMor	N-nitrosomorpholine
NP	Nanoparticle
NPIP	N-nitrosopiperidine
NTP	National Toxicology Program
OR	Odds ratio
PAH	Polycyclic aromatic hydrocarbons
PARP	Poly(ADP-ribose) polymerase
PBNA	Phenyl-β-naphthylamine
PCB	Polychlorobiphenyl
PCDD	Polychlorinated dibenzo-para-dioxins
PCP	Pentachlorophenol
PCR	Polymerase chain reaction
PeCDF	2,3,4,7,8-Pentachlorodibenzofuran
PKC	Protein kinase C
POG	Paediatric oncology group
ppb	Parts per billion

ppm	Parts per million
ppt	Parts per trillion
PVC	Polyvinyl chloride
ROS	Reactive oxygen species
RR	Relative risk
SCE	Sister chromatid exchange
SES	Socioeconomic status
TCDD	Tetrachlorodibenzo-p-dioxin
TCE	Trichloroethylene
TEF	Toxicity equivalence factor
TWA	Time-weighted average
USA	United States of America
VC	Vinyl chloride
VCM	Vinyl chloride monomer
VOC	Volatile organic compound
wk	Week
yr	Year
ZDEC	Zinc-diethyldithiocarbamate

Pesticide and Xenobiotic Metabolism in Aquatic Organisms

Akhila D S, Priyanka Ashwath, Kavitha Guladahalli Manjunatha, Sadanand Dangari Aksahy, Raghvendra Rao, DeviPrasadh Reddy, and Rajeshwari Vittal

1 Introduction

Scientific, technological, and industrial revolutions have permitted humans to overutilize the resources, thereby creating an imbalance in the natural ecosystem (Sikandar et al. 2013). Enormous amounts of toxic effluents let out as a result of industrial processes have caused widespread contamination of the ecosystem. It was reported that nitrated and halogenated hydrocarbons are few among the major contaminants (Jain et al. 2011). Various fertilizers, insecticides, and herbicides have been employed in agricultural activities. In addition, industry-based synthetic compounds like dyes, pharmaceuticals, hydraulics, pigments, agrochemicals, halogenated compounds, and fire retardants have been extensively used (Reineke and Knackmuss 1988). Due to the inevitable uses in veterinary and anthropoid medications, pharmaceutical wastes have developed as a significant cause of prolonged environmental condition (Gani et al. 2021). The chemicals thus let out into the surrounding environments are believed to possess specific modes of action and thus impart a certain number of hazards on the aquatic flora and fauna, in comparison to the other chemical substances. These chemical compounds persist within the environment making them a potential agent causing health hazards and posing toxic effects on the surrounding niche. Xenobiotics can have a range of impacts, such as

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immunological reactions, medicine toxicity, and climate change. Xenobiotics are substances that are either nonbiodegradable or only partially biodegradable, which may result in sluggish biotransformation and persistence in the setting for an extended period of time (Dar et al. 2020).

With this point of view, in this chapter, we sought to discuss dormant pollutants (pesticides and xenobiotics), their metabolism, and their harmful effects on aquatic life.

2 Pesticides and Xenobiotics

Pesticides are a collective term used to represent all the compounds including herbicides, insecticides, and fungicides that are applied to regulate pests or undesirable organisms. Water resources contaminated with pesticides are found to affect both humans and the ecosystem. Pesticides have sought to be as probable mutagens, as they are capable of triggering deviations in the DNA. The World Health Organization has estimated that around 1,000,000 human beings have been affected by acute poising as a result of toxicant contact; in addition, annually, a death rate ranging between 0.4% and 1.9% has been recorded. It has been reported that constant exposure to pesticides in the medium and long term resulted in various syndromes and tumors including the nervous system disorder. Accustomed application of agrochemicals such as pesticides, soil conditioners, acidifying agents, chemicals involved in animal husbandry (hormones and antibiotics), and fertilizers is popular. Since the beginning of the industrial era in 1950, the use of pesticides has had a severe impact on the environment niche. It has been extensively employed as a pest control agent wherein monocular cultivation is involved. Few demerits are still involved, despite the development of chemistry in the field of pesticide formulations; majorly, the pesticides perturb the predator-prey interactions, thus causing an imbalance in the biodiversity. Furthermore, the pesticides can cause exceptional health concerns. Though the usage of a few chemical compounds is limited/controlled by the agricultural sector, it is said that agriculture is one of the areas which purposefully discharges chemicals into the surrounding niche leading to the adverse effects (WHO 2020; Warra and Prasad 2020). Of the manufactured compounds, the usage of the pesticides by the agricultural sector has been recorded the highest (Sharma et al. 2019; Laxmi et al. 2019). It is often difficult to distinguish among the pesticide effect and environmental effects on the ecosystem because the industrial effluents are let out into the surroundings to a greater extent accidently or intentionally. On the contrary, significant evidence suggests that the usage of pesticides in the agricultural field has had a considerable impact on the water quality causing major influence and concerns on the environment (FAO 1990; Warra and Prasad 2020). Despite the fact that the amount of pesticide practice is relatively extensive, it is plausible that substantial use of chemicals is associated only with few pesticide products. Of the million tons of pesticides produced, 29.5% insecticides, 47.5% herbicides, 5.5% other pesticides, and 17.5% fungicides are the categories extensively in application

(De et al. 2014). Howbeit, the use of pesticides is in a range of low to zero in subsistence and conventional farming in countries like Asia and Africa. However, the environment, water quality, and health hazards are associated with its inappropriate usage.

2.1 Classification of Pesticides

Pesticide is a collective term that describes diverse groups of insecticides, herbicides, rodenticides, garden chemicals, fungicides, and household disinfectants employed to both protect and destroy pests (Mohapatra et al. 2021). Each pesticide groups differ in its physical and chemical properties. On that account, it is preferable to classify them based on their properties. As recommended by Drum (1980), the widely used method of classification of pesticide groups depends on their (a) chemical structure, (b) mode of entry, and (c) mode of action and type of organisms they target (Yadav et al. 2015). Based on their source, chemical pesticides have been classified into four types: pyrethroid pesticides, organophosphate, carbamate, and organochlorine (Yadav and Devi 2017). Another class of pesticides are biopesticides, occurring naturally or are naturally derived from living organisms such as bacteria, plants, and fungi (Mehrotra et al. 2017). Microbial pesticides, biochemical pesticides, and incorporated protectants are the three major groups of biopesticides.

2.2 Pesticide Categories

2.2.1 Chemical Structure of Pesticides

The most general and applicable method of classifying insecticides is based on their chemical description and the chemical composition of the active ingredients. The chemical classification of pesticides delivers the efficacy and physical and chemical properties of special pesticides (Fig. 1).

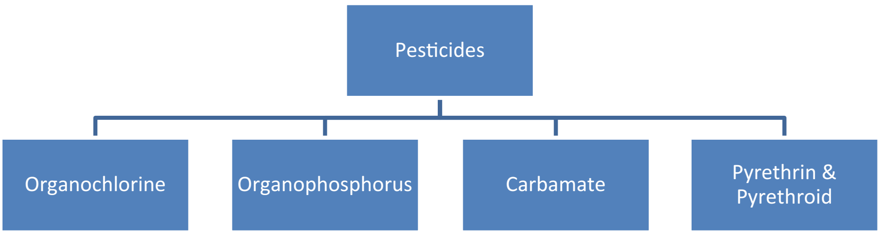

Fig. 1 Classification of Pesticides

2.2.2 Organochlorine Pesticides (OCPs)

Chemicals belonging to this group are very stable and persistent in the environment and have the potential of accumulating in the adipose tissue (Lee et al. 2017). It is said that in humans, these chemicals/their metabolites largely work on the central nervous system by altering their electrophysiological properties and altering enzymatic nerve membranes and changing the flow kinetics of K+ and Na+ through the nerve cell membrane and may cause seizures from apnea and acute poisoning death (Zaffar et al. 2016). Based on their structure, the organochlorines are categorized into five categories: (a) hexachlorocyclohexane (HCH), such as lindane, (b) DDT and its analogues including DDT and dichlorodiphenyldichloroethylene (DDE), (c) dichlorodiphenyldichloroethane (DDD), (d) mirex and chlordecone, and (e) cyclodienes including aldrin, dieldrin, endrin, heptachlor, chlordane, and endosulfan (Singh and Singh 2017). Higher concentrations of most of the OCPs generally result in acute toxicity and death under natural circumstances and may be gradually causing chronic illness. The persistent nature of the OCPs and their lipophilic nature might lead to long-term storage in the adipose tissue, following their release into the circulatory system (Kumar et al. 2013). This process takes a longer duration from the initial time of exposure to the onset of effects; it is said that DDT may remain in the human body for 50 years and more.

Organophosphate Pesticides

Organophosphate pesticides are ester derivatives of phosphoric acid. These esters work on the central nervous system by blocking acetylcholine. This enzyme is responsible for maintaining the levels of acetyl cholinesterase, which disturbs the nerve impulse by the phosphorylation of the serene OH group in the active site of the enzyme (Lionetto et al. 2011; Laxmi et al. 2020). Headache, dizziness, loss of reactions, nausea, convulsions, cramps, and ultimately coma and death are the intoxication symptoms of organophosphate pesticides.

Atropine is said to be the definitive treatment for organophosphate poisoning, which competes with acetylcholine at the muscarinic receptors. The recommended initial dose for adults is 2–5 mg IV, and for children, a dosage of 0.05 mg/kg IV is recommended. In case the patient does not respond to the initial doses, the dosage is doubled every 3–5 min until the respiratory secretions have been cleared and there are no signs of bronchoconstriction (van Heel and Hachimi-Idrissi 2011). The atropine is given as a continuous infusion or in bolus in patients with severe poisoning for a couple of days until the patient shows any signs of improvement.