Fungal Biology

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Mycoremediation and Environmental Sustainability

Volume 3

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Fungal Biology

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Fungal biology has an integral role to play in the development of the biotechnology and biomedical sectors. It has become a subject of increasing importance as new fungi and their associated biomolecules are identified. The interaction between fungi and their environment is central to many natural processes that occur in the biosphere. The hosts and habitats of these eukaryotic microorganisms are very diverse; fungi are present in every ecosystem on Earth. The fungal kingdom is equally diverse, consisting of seven different known phyla. Yet detailed knowledge is limited to relatively few species. The relationship between fungi and humans has been characterized by the juxtaposed viewpoints of fungi as infectious agents of much dread and their exploitation as highly versatile systems for a range of economically important biotechnological applications. Understanding the biology of different fungi in diverse ecosystems as well as their interactions with living and non-living is essential to underpin effective and innovative technological developments. This series will provide a detailed compendium of methods and information used to investigate different aspects of mycology, including fungal biology and biochemistry, genetics, phylogenetics, genomics, proteomics, molecular enzymology, and biotechnological applications in a manner that reflects the many recent developments of relevance to researchers and scientists investigating the Kingdom Fungi. Rapid screening techniques based on screening specific regions in the DNA of fungi have been used in species comparison and identification, and are now being extended across fungal phyla. The majorities of fungi are multicellular eukaryotic systems and therefore may be excellent model systems by which to answer fundamental biological questions. A greater understanding of the cell biology of these versatile eukaryotes will underpin efforts to engineer certain fungal species to provide novel cell factories for production of proteins for pharmaceutical applications. Renewed interest in all aspects of the biology and biotechnology of fungi may also enable the development of “one pot” microbial cell factories to meet consumer energy needs in the 21st century. To realize this potential and to truly understand the diversity and biology of these eukaryotes, continued development of scientific tools and techniques is essential. As a professional reference, this series will be very helpful to all people who work with fungi and should be useful both to academic institutions and research teams, as well as to teachers, and graduate and postgraduate students with its information on the continuous developments in fungal biology with the publication of each volume.

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Preface

Mycoremediation is a process of bioremediation in which fungal-based technology is used to decontaminate the environment. Fungi have been confirmed to be a very cost-effective and environmentally sound way for helping to remove an extensive array of contaminants from damaged environments or wastewater. The contaminants include heavy metals, persistent organic pollutants [polycyclic aromatic hydrocarbons (PAHs), pesticides, and herbicide], textile dyes, leather tanning industry chemicals and wastewater, petroleum fuels, pharmaceuticals, and personal care products. The by-products of the remediation can be appreciated constituents themselves, such as enzymes (like laccase) and edible or medicinal mushrooms, making the remediation process even lucrative. Mycoremediation practices involve placing of mycelium into contaminated soil and placing mycelial mats over toxic sites or a combination of these techniques in one or more treatments. Toxins in our food chain (including heavy metals, PCBs, and dioxins) become more concentrated at each step, with those at the top being contaminated by ingesting toxins consumed by those lower on the food chain. Fungal mycelia can destroy these toxins in the soil before they enter our food supply.

Fungi are among the primary saprotrophic organisms in an ecosystem, as they are efficient in the decomposition of material. Wood-decay fungi, especially white rot, secrete extracellular enzymes and acids that break down lignin and cellulose. Fungi feature among nature's most vital agents for the decomposition of waste matter and are crucial components of the soil food web, providing nourishment for the supplementary biota that live in the soil environment. The degree of sustainability of the physical environment is an index of the survival and well-being of the all-inclusive components in it. Additionally, it is not sufficient to try disposing toxic/deleterious substances with any known method. The best method of sustaining the environment is to return all the components (wastes) in a recyclable way so that the waste becomes useful and helps the biotic and abiotic relationship to maintain an aesthetic and healthy equilibrium that characterizes an ideal environment.

This book should be immensely valuable for researchers, technocrats, policy makers, and scientists of fungal biology and those who are interested in environmental sustainability. We are honored that leading scientists who have extensive, in-depth understanding and expertise in fungal biology and environmental concern took the time and effort to develop these outstanding chapters. Each chapter is written by globally recognized academicians, so the reader is given an up-to-date and detailed account of our knowledge of the fungal system and numerous applications of fungi.

We are indebted to the many people who helped bring this book to light. The Editors wish to thank Series Editors Dr. Vijai Kumar Gupta and Dr. Maria G. Tuohy as well as Dr. Eric Stannard, Senior Editor, Botany, Springer, for their generous assistance, constant support, and patience in initializing the volume. Editors in particular are very thankful to Springer's Nicholas DiBenedetto, Anthony Dunlap, and Rahul Sharma (Project Coordinator) for the kind care and constant encouragement received. Ram Prasad thanks honorable Vice Chancellor Dr. Sanjeev Kumar for continuous support and inspiration in putting everything together. Special thanks are due to our well-wishers and friends.

Motihari, Bihar, India — Ram Prasad
Mysore, India — S. Chandra Nayak
Varanasi, India — Ravindra Nath Kharwar
Varanasi, India — Nawal Kishor Dubey

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About the Editor

Ram Prasad is associated with the Department of Botany, Mahatma Gandhi Central University, Motihari, Bihar, India. His research interest includes applied and environmental microbiology, plant–microbe interactions, sustainable agriculture, and nanobiotechnology. Dr. Prasad has more than one hundred seventy five publications to his credit, including research papers, review articles and book chapters and five patents issued or pending, and edited or authored several books. Dr. Prasad has 12 years of teaching experience and has been awarded the Young Scientist Award and Prof. J.S. Datta Munshi Gold Medal by the International Society for Ecological Communications, FSAB Fellowship by the Society for Applied Biotechnology, the American Cancer Society UICC International Fellowship for Beginning Investigators; Outstanding Scientist Award in the field of Microbiology by Venus International Foundation; and BRICPL Science Investigator Award and Research Excellence Award. He has been serving as Editorial Board Member of *Frontiers in Microbiology, Frontiers in Nutrition*, *Archives of Phytopathology and Plant Protection*, *Phyton-International Journal of Experimental Botany*, *Biocell, IET Nanobiotechnology*, and *Journal of Renewable Materials* as well as Series Editor of *Nanotechnology in the Life Sciences*, Springer Nature, USA. Previously, Dr. Prasad served as Assistant Professor at Amity University Uttar Pradesh, India; Visiting Assistant Professor, Whiting School of Engineering, Department of Mechanical Engineering, Johns Hopkins University, Baltimore, United States; and Research Associate Professor at the School of Environmental Science and Engineering, Sun Yat-sen University, Guangzhou, China.

S. Chandra Nayak is an Agricultural Biotechnology Researcher specialized in the application of biotechnology/nanotechnology tools in plant protection, pathogen detection, and plant–pathogen interaction. He has 20 years of experience in research, including Visiting Scientist at Danish Government Institute of Seed Pathology, Denmark; China Agricultural University, Beijing, China; and Principal Investigator for thirteen ICAR-AICRP-Pearl Millet Pathology Research Centre. Dr. Nayak is one of the members of the team that established the Asian Seed Health Centre at the University of Mysore, with the assistance from DANIDA, Denmark. His laboratory is one of the leading research laboratories on seed health and plant protection research in India. Dr. Nayak is recipient of the prestigious Japan International Award for Young Agricultural Researchers and The Millennium Plaques Honor (Prime Minister Award for Contribution in the field of Science & Technology) by the Indian Science Congress Association, DST, Govt. of India. Dr. Nayak has more than 2000 research citations with 27 h Index and 4 national patents; published 90 research articles in reputed national and international journals, 8 books, 15 book chapters (CABI/Springer/Elsevier/Nova Science, etc.), 3 application notes (Agilent Technologies, USA), 6 technical bulletins, and 16 short publications/popular articles; and submitted more than 1000 nucleotide sequences of seed-borne pathogens and bio-control agents to NCBI-USA, EMBL-Europe, and DDBJ-Japan database.

Ravindra Nath Kharwar is currently serving as a Professor at the Centre of Advanced Study in Botany, Institute of Science, Banaras Hindu University, Varanasi. He has over 30 years of experience in teaching and research. Prof. Kharwar has more than 90 research papers, 11 reviews in journals of repute, and over 22 book chapters are to his credit. The highest impact factors of journals in which he has published are 14.34 and 12.00, that is, *Trends in Biotechnology* and *Natural Product Reports*. He is Fellow of the Mycological Society of India, the Indian Phytopathological Society, and BOYSCAST and is the recipient of Dr. S.K. Shome Memorial Lecture Award in 2012, Dr. V. Agnihothrudu Memorial Lecture Award in 2016, Dr. AK Sarbhoy Memorial Award in 2019, and Professor P.C.Jain Memorial Award in 2021.

Prof. Kharwar is associated with various reputed journals in capacities of either Editor-in-Chief/Editor or member of editorial board. He has worked with Prof. Gary Strobel, Department of Plant Sciences, Montana State University, Bozeman, USA, as a BOYSCAST Fellow. Prof. Kharwar has been working on fungal and actinobacterial endophytes. His research focus is on isolation, purification, and characterization of bioactive molecules from fungal and actinobacterial endophytes along with documenting their diversity and ecology. Abiotic stress alleviation and metal removal activities are also performed. He has been conducting epigenetic study for cryptic metabolites from endophytic microbes. In addition, endophytes derived biosynthesis (Green Synthesis) of metal nanoparticles and their usages and understanding the mechanism of induced resistance in plants against diseases by using endophytes/or PGPR are also his focus points. He has guided 15 Ph. D. candidates and over 50 dissertation students, and 8 Ph.D. students are working currently under him. Prof. Kharwar has visited countries like Iran, UAE, the Netherland, the USA, Sweden, China, and Thailand in different capacities.

Nawal Kishor Dubey has significantly contributed to the important area of botanical pesticides. He has formulated several novel plant-based preservatives that exhibit significant potency in control of biodeterioration of food from fungi, mycotoxins, and insects as well as from lipid peroxidation. Prof. Dubey has been granted 3 patents; published 360 research papers, review articles, and 13 books; and is a recipient of several awards including Prof. M. J. Narshimhan Award and Young Scientist Award. He acted as Chairperson, Session Coordinator, and Key Speaker at the 9th ICPP 2008, held between August 24 and 29, 2008, Torino, Italy. Dr. Dubey has been awarded several fellowships: Visiting Fellow, University of Iri, South Korea, under INSA Exchange (1991); Tokyo University of Pharmacy and Life sciences, Tokyo, Japan, under INSA-JSPS Exchange Programme (1996); INSA visiting Fellow CFTRI, Mysore (1995). He has been invited Professor at the University De French, Besancon, France (1997), and Kings College, London, under INSA-Royal Society Exchange Programme for 3 months (2001) and Coordinator, for Applied Microbiology at BHU (2012–2015). Prof. Dubey has been Fellow and Member of National Academy of Sciences (FNASc) and National Academy of Agricultural Sciences (NAAS), India.

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Chapter 1
Bioremediation of Toxic Pesticides in Soil Using Microbial Products

O. P. Abioye, U. J. J. Ijah, S. A. Aransiola, S. H. Auta, and M. I. Ojeba

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1.1 Introduction

Soil pollution is a serious global threat and, hence, an effective remediation technology is of great importance (Abioye et al. 2019). Rapid industrialization along with increasing population has resulted in a wide accumulation of chemicals (Aransiola et al. 2013). The recurrence and enormous utilization of 'xenobiotic' chemicals have prompted an amazing push toward new innovations in order to reduce or eliminate these contaminants from the environment. The techniques traditionally used for the

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remediation of polluted sites (e.g., recycling, landfilling, pyrolysis, and incineration) affect the environment as well, which can cause the release of toxic intermediates (Debarati et al. 2005; Prasad 2021). Moreover, these techniques are expensive and sometimes difficult to execute, particularly in broad agricultural areas (Jain et al. 2005). One promising technique is bioremediation which exploits the capacity of microorganisms to expel toxins from polluted environment, an option that is viable, negligibly hazardous, economical, flexible, and environmentally friendly (Finley et al. 2010). Pesticides have turned into an unavoidable part of present-day agriculture because of their need in economical pest management and in the enhancement of product quality (Gouma 2009). Be that as it may, increased use of pesticide significantly affects climate, around 90% of pesticides applied by farmers failed to completely achieved the set objectives as it affect farmers health directly, escaped into the soil, air and washed into water bodies. Out of the aggregate unpredictable outflow to nature, 63% are pesticides (Yates et al. 2011). Overall, their capacity to collect into the tissues of living beings prompting bioaccumulation is the real concern. Each of these factors contributes to environmental contamination and significant strides are taken to handle this issue. The conventional methods utilized for the treatment of these contaminants are compelling and additionally have certain disadvantages; for example they are expensive and the quality of these procedures is low. Likewise, most of the time, these systems are not adequate (Dixon 1996). Pesticide management should essentially maintain soil quality which is of high concern. Pesticides constitute the key control system for crop pest and disease management. Nonstop application of these pesticides to the soil and aquatic system poses risks to well-being and results in environmental contamination, which has activated much open concern. Consistence application of these pesticides throughout the years has brought about issues created by their cooperation with the biological framework in nature. Despite the risks, pesticides will continue to be a crucial component in agriculture in years to come as there is no reasonable other option to absolutely supplant them. Considering the lethal impact of the pesticides, it is fundamental to expel them from the environment with appropriate remediation measures. Bioremediation is one of the current methods utilized for environmental cleanup. In this process, heterotrophic microorganisms are used to separate carbon and other vital compounds from perilous mixtures. Organophosphorous compounds alone compensate for 70% of the pesticides utilized around the world.

It has been found that microorganisms can alter and degrade xenobiotics; researchers have been investigating different microbial qualities, especially around polluted environments looking for microorganisms that can help in the remediation of an extensive variety of contaminations. Subsequently, biotransformation of environmental contaminants in the regular habitat has been widely considered to comprehend microbial ecology, physiology, and development because of their bioremediation potential (Mishra et al. 2001; Kumar M et al. 2017; Kumar V et al. 2017). The biochemical and genetic basis of microbial degradation has gotten impressive consideration. A few genes/enzymes, which furnish microorganisms with the capacity to remediate organopesticides, have been recognized and portrayed. In this manner, microorganisms has proved to be a better and safer option in the biodegradation of pesticides. The capacity of these microorganisms to degrade xenobiotics is specifically connected to their adaptation to conditions where these compound exist. Also, genetic engineering might be utilized to upgrade the properties of such microorganisms that have the desirable characteristics required for biodegradation (Schroll et al. 2004). Around 30% of agricultural produce is lost because of pests. Consequently, increased utilization of pesticides has turned out to be irreplaceable in agribusiness and has become a part of agribusiness. Nonetheless, the unpredictable utilization of pesticides also poses serious threats and issues to people and the biodiversity (Gavrilescu 2005; Hussain et al. 2009). Environmental pollution caused by pesticides is also noted in regions where pesticides are not used. The agricultural pesticides applications gets to the soil and can diffuse quickly until it reaches the water table at noticeable concentration which affects different categories of living organisms. Therefore, the fate of pesticides is unpredictable and they can degrade different regions apart from where they were initially utilized. Hence, cleaning pesticide-contaminated zones becomes an extremely complex errand (Gavrilescu 2005).

Organochlorine pesticides were generally in use during the 1970s, especially in the United States. Although their utilization has been ousted in numerous nations, they are still used in many developing countries. Organochlorine pesticides get aggregated in living beings and pose interminable risks to well-being, for example, cancer, neurological, and teratogenic impacts (Vaccari et al. 2006). Numerous xenobiotic compounds are unmanageable and resistant to biodegradation, especially organochlorine pesticides (Chaudhry and Chapalamadugu 1991; Dua et al. 2002). As a result, these exceedingly dangerous and cancer-causing compounds hold on in the environment for a relatively long time. But in reality organophosphorus pesticides are generally utilized in the United States. These pesticides affect the nervous system of insects and humans, in addition to influencing the reproductive system (Colosio et al. 2009; Jokanovic and Prostran 2009). Increased utilization of organophosphorus in agribusiness has begun to result in different environmental issues (Singh and Walker 2006). In spite of the fact that these pesticides degrade rapidly in water, there is a possibility that the buildups and by-products of these pesticides remain in unsafe levels in living beings (Silva et al. 1999; Ragnarsdottir 2000). Carbamate pesticides are imperative in the farming because of their wide movement range. Notwithstanding an extensive variety of compound, they are moderately pollute the environment and for the most part are less harmful to people (Wolfe et al. 1978). Nonetheless, they interfere with the activity of enzyme acetylcholinesterase, thereby inhibiting the hydrolysis of acetylcholine (AcH) which results in the accumulation of AcH. This leads to different manifestations, for example, sweating, lacrimation, hypersalivation, and convulsion of extremities (Suzuki and Watanabe 2005). Hence, this class of pesticides are considered lethal. Cleaning the pesticide-infested environment is a troublesome matter and can be exorbitant. Indeed, the negative effects from pesticides in the environment are for all intents and out-weighed its usefulness. Any measure used to diminish the impacts of pesticides on the environment will only be a palliative measure and not a solution. Unfortunately, there is a constant threat to the organisms and environment, for instance, the annihilation of the avian species and microorganisms on the planet. Organic strategies are more reliable to disinfect regions that have been contaminated by pesticides. These techniques use a large number of microorganisms in the environment, whose specific end goal is to eliminate pesticides from the contaminated zone. Numerous native microorganisms develop complex and viable metabolic pathways that allow the biodegradation of pollutants that are discharged into nature. In spite of the fact that the metabolic procedure is long, it is considered a more suitable option for evacuating the wellsprings of xenobiotic compound and the contamination they cause (Diaz 2004; Schoefs et al. 2004; Finley et al. 2010). By virtue of the deadly dangers synthetic pesticides stance to the living beings, there is an unending quest for environmentally friendly pesticides that can support agricultural enterprise. Organic pesticides depend on common exacerbates that viably control the invasion of bugs in agribusiness. As opposed to synthetic pesticides, organic pesticides are advantageous in that they are efficient and do not cause inadvertent blowback (Gerhardson 2002; Raaijmakers et al. 2002; Fravel 2005). This chapter discusses the degradation of pesticides using microorganisms and their metabolites. This topic is infinite, and we are going to underscore the most recent points, including studies on the biodegradation of organochlorine, organophosphorus, and carbamate pesticides by microbiological processes.

1.2 Pesticides

A pesticide can be defined as any substance or mixture of substances that counteract, devastate, repulse, or destruct any pest (e.g., nematodes, insects, parasites, rats, weeds). Pesticides like herbicides, fungicides, and insecticides and different materials are utilized to control pests (EPA 2015).

Every year, millions of tons of pesticides are used throughout the world. The expenditures on pesticides were 35.8 billion in 2006, which increased to 39.4 billion US dollars in 2007. One of the essential concerns is to limit hurtful impacts brought by organisms including viruses, bacteria, fungi and insects (Liu et al. 2001). The broad utilization of pesticides causes environmental worries, as just 5% or less from the applied pesticides achieve the objective living beings which brought about contamination of soil and water bodies (major environmental problem of current age). Occasional utilization of pesticides results in the process of pesting. This redundancy in the long time application without remediation, essentially prompts pesticides and their deposits in the environments, endangering the whole populace by their multifaceted toxicity (Bouziani 2007).

1.2.1 Types of Pesticides

Synthetic pesticides (Table 1.1) offer many benefits to agriculture; however, as discussed before, they are lethal to other non-target life forms and cause environmental contamination. Therefore, research works are focusing on new pests control choices due to the impacts of these compounds on human well-being and on the environment. The persistence of pesticides in soil differs from 7 days to quite a while relying on the

Table 1.1 Summary of types of pesticides and their effects

Pesticides	Class	Examples	Health effects
Insecticides	Organophosphates	Parathion, malathion, methyl parathion, chlorpyrifos, diazinon, dichlorvos, phosmet, fenitrothion tetrachlorvinphos and azinphos methyl	Neuropathy, myopathy, tremors, irritability, convulsions, inhibiting the enzyme acetylcholinesterase, paralysis
	Carbamates	Aldicarb, carbofuran (Furadan), fenoxycarb, carbaryl (Sevin), ethienocarb and fenobucarb	Inhibition of acetylcholinesterase enzyme, paralysis
	Organochlorines (dichlorodiphenyle thanes and cyclodienes)	DDT, dicofol, heptachlor, endosulfan, chlordane, aldrin, dieldrin, endrin, mirex and pentachlorophenol	Stimulation of the nervous system by disrupting the sodium/potassium balance of the nerve fiber, tremors, irritability, convulsions, hyperexcitable state of the brain, cardiac arrhythmiatic and reproductive problems
Herbicides	Phenoxy and benzoic acids, triazines, ureas, and Chloroacetanilides	Chlorophenoxy acids, hexachlorobenzene (HCB), Picloram, atrazine, simazine, propazine, diquat, paraquat, oxyfluorfen, alachlor, fluroxypyr	Dermal toxicity, carcinogenic effect, damage to the liver, thyroid, nervous system, bones, kidneys, blood and immune system.
Fungicides	Substituted benzenes, thiocarbamates, thiophthalimides, organomercury compounds, etc.	Chloroneb, chlorothalanil, hexachlorobenzene, ferbam, metam sodium, thiram, ziram, ethyl mercury	Damage to the liver, thyroid, nervous system, bones, kidneys, blood and immune system, carcinogenic property also
Rodenticides	Coumarins,1,3-indandione	Warfarin, coumatetralyl, difenacoum, brodifacoum, flocoumafen, bromadiolone diphacinone, chlorophacinone, pindone	
Nematicides		Aldicarb, dibromochloropropane	
Bactericides		Metiram, difolatan	
Botanicals		Perethrin, permethrin	

structure of the pesticide and penetration through the soil. For instance, the exceedingly toxic phosphates do not hold on for more than 3 months, while chlorinated hydrocarbon insecticides like chlordane are known to continue in any event for 4–5 years and a few times over 15 years. Constancy of pesticides represents a danger to domesticated animals and human well-being. Longer aplications of pesticides prompts the amassing of its deposits in soil which may come about into the expanded bioaccumulation by plants to the level at which the utilization of plant items may demonstrate harmful to human being and also animals. Pesticides buildups in different environmental frameworks (soil and additionally water) have been reported around the world.

1.2.2 Biological Pesticides

As per the Environmental Protection Agency (EPA 2015), biopesticides are characterized as naturally occurring pest control substances. They are categorized into three groups (Joshi 2006):

Microbial pesticides: a microbial living thing (microorganisms, protozoans, parasites) is the dynamic control agent

Plant pesticides: pesticidal substances produced by plants from presented genetic material (plant consolidated protectants)

Biochemical pesticides: naturally occurring substances that control pests by non-toxic components. These incorporate substances that meddle with development or mating, for example, pheromones.

The good thing about biopesticides is their safety to non-target life form, biodegradability and their specificity, which allows the utilization of little measurements and power presentation, thus maintaining a strategic distance from contamination created by conventional pesticides (Rosell et al. 2008). Notwithstanding being less harmful than chemical pesticides, biopesticides are significantly utilized in integrated pest management (IPM) procedures, where they incredibly diminish the utilization of chemicals, thereby increasing harvest yields. The specificity of biopesticides varies widely depending on their chemical counterparts.

1.2.2.1 Organochlorine, Organophosphate, and Carbamate Pesticides

Organochlorine pesticides (Fig. 1.1) are being used widely throughout the world for public health and farming purposes. As of now, their utilization is being eliminated in light of their toxic quality, environmental industriousness and collection in the environmental way of life. Hexachlorocyclohexane (HCH) is a standout among the most widely used organochlorine pesticides for both agriculture and medical purposes. Although the use of a specialized mixture containing eight stereoisomers of organochlorine compounds was restricted in a few developing countries in the 1970s, many developed nations continue to use lindane (γ-HCH) for monetary reasons. Hence, new destinations are consistently being polluted by γ-HCH and its stereoisomers (Blais et al. 1998; Iwata et al. 1993).

As of now, among the different groups of pesticides used around the world, organophosphorus pesticides are the major and most widely used, accounting for more than 36% of the total world market. The most utilized among these is methyl parathion. Its accumulation causes numerous health risks; therefore, its degradation becomes vital (Ghosh et al. 2010). Organophosphorus pesticides (OP) are esters of phosphoric acid, also called organophosphates, which includes aliphatic, phenyl, and heterocyclic derivatives (Fig. 1.2). Organophosphates are used to control the

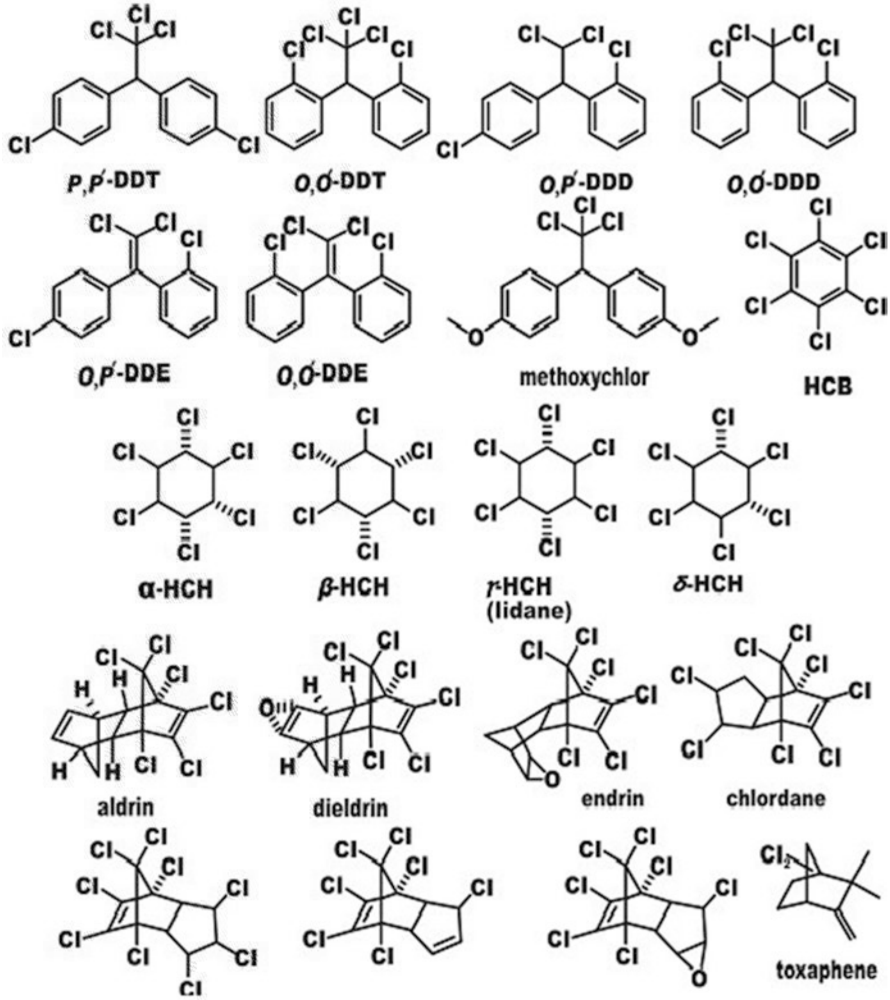

Fig. 1.1 Structure of organochlorine pesticide

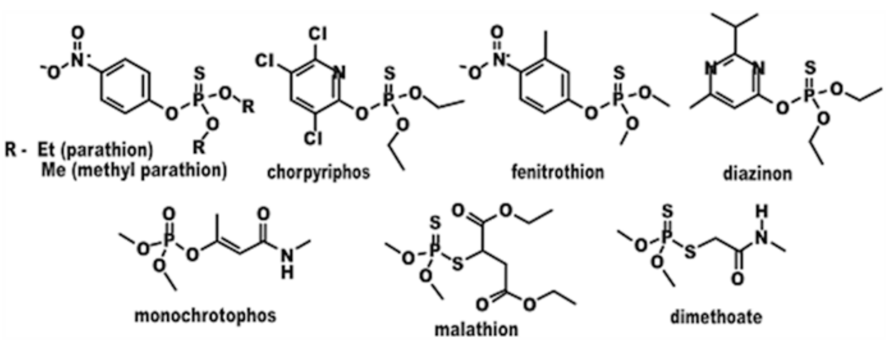

Fig. 1.2 Structure of organophosphate pesticide

sucking, biting, and boring insects, arachnid, aphids, and pests that assault crops like cotton, sugarcane, peanuts, tobacco, vegetables and other products of the soil. Organophosphorus pesticides are advertised by a considerable lot of the world's major agrochemical organizations. Few principal agricultural products are parathion, methyl parathion, chlorpyriphos, malathion, monocrotophos, diazinon, fenitrothion, and dimethoate (Fig. 1.2).

Carbamates were introduced as pesticides in the early 1950s and are still used extensively in pest control due to their effectiveness and broad spectrum of biological activity (insecticides, fungicides, herbicides). High polarity and solubility in water and thermal instability are typical characteristics of carbamate pesticides, as well as high acute toxicity. The carbamates are transformed into various products in consequence of several processes such as hydrolysis, biodegradation, oxidation, photolysis, biotransformation, and metabolic reactions in living organisms (Soriano et al. 2001). Chemically, the carbamate pesticides are esters of carbamates and organic compounds derived from carbamic acid (Fig. 1.3). This group of pesticides can be divided into benzimidazole-, *N*-methyl-, *N*-phenyl-, and thiocarbamates. The compounds derived from carbamic acid are probably the insecticides with the widest range of biocidic activities (Sogorb and Vilanova 2002).

1.2.3 Importance of Pesticides

The important goal of using pesticides in agricultural fields is to control vermins and disease vectors. This has been ponder upon as human efforts through research could be used in expanding agricultural yields and enhancing general wellbeing when pesticides are applied (Helweg 2003). Pesticides discharged into the environment may have a few unfriendly environmental impacts extending from long time impacts to numerous changes in biological community. In spite of the great consequences of utilizing pesticides in agriculture and public health, their utilization is typically with pernicious environmental and general well-being impacts. Pesticides are considered remarkable environmental contaminants because of their high organic toxicity (acute and chronic). Pesticides by definition are lethal compound operators. A pesticide is normally equipped with harmful substances to all types of life other than the focused pests. Because of this property, they can be best defined as biocides (fit to destroy all forms of life). Albeit a few pesticides are produced to be specific in their method of action, that their scope of selectivity is just restricted to the targeted pest.

Fig. 1.3 General structures of carbamate pesticides