

Mohidus Samad Khan
Mohammad Shafiur Rahman *Editors*

Pesticide Residue in Foods

Sources, Management, and Control

 Springer

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ISBN 978-3-319-52681-2 ISBN 978-3-319-52683-6 (eBook)
DOI 10.1007/978-3-319-52683-6

Library of Congress Control Number: 2017933567

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Printed on acid-free paper

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The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

Food is essential for life, society, and culture. However, foods can be easily contaminated through the use of different pesticides, chemicals, heavy metals, growth hormones, and preservatives during the pre-harvesting and post-harvesting periods. Pesticides are chemical substances used to kill or control various types of pests, which are hazardous for crops and animals. A wide range of chemicals, such as insecticides, herbicides, fungicides, animal repellent, and antimicrobial substances, are categorized as pesticides. These chemical substances are often persistent, contaminate the soil and water resources, and may remain on or in foods after these are applied to crops and animals. A good percentage of the sprayed pesticides also accumulates in soil and water sources, which possesses a long-term threat of entering into the food chain and could accumulate in the human body.

There are direct and indirect health hazards associated with regular consumption of foods with pesticide residues. Scientists have reported that pesticide residues in foods can cause serious health issues including cancers, neurological impairment, organ failure, liver diseases, lung infections, heart diseases, respiratory tract infection, and development and reproductive effects. Consumers and different environmental groups have strongly accentuated on managing and monitoring pesticide residues in foods. Different international, regional, and local authorities have developed food standards, guidelines, laws, and regulations to monitor in order to restrict pesticide residues in foods. Scientists are working to offer safer alternatives of conventional pesticides. In recent years, consumers are showing an increased interest in organic foods due to detrimental health effects of chemicals used in food production. However, without pesticide use, food production yields would be extremely low, which could raise the food price very high. Therefore, a proper risk-benefit analysis needs to be done before using any types of pesticides.

The book entitled “Management and Control of Pesticide Residue in Foods” discusses the sources of pesticide residues in foods, analytical methods for the qualitative and quantitative detection of pesticides in foods, relevant health and environmental concerns, and available laws and regulations to address pesticide-related issues. In addition, different pesticide management techniques including the reduction of pesticide residues in grains, alternatives of conventional pesticides, and

prospects of organic farming are discussed. The brief descriptions of the chapters are as follows:

Chapter 1 presents a brief introduction of pesticide origin and pesticide residues in foods, health and environmental impact of pesticide residues, and laws and regulations to regulate pesticide use. The management of pesticide handling and use, analytical techniques to detect pesticide residues, and alternatives of pesticides are also briefly addressed in this chapter.

Chapter 2 presents a brief history of pesticide use from a toxicological point of view. Pesticide active ingredients were categorized and analyzed according to their toxicities. The rise and subsequent decline and fall of certain pesticide active ingredients are also discussed. The toxicity, exposure, and risk related to pesticide use are distinguished, and the risks associated to pesticides are defined as a function of toxicity and exposure.

Chapter 3 addresses the laws and regulations developed and practiced in different countries to regulate pesticide production, sales, and applications. The international conventions and codes of conduct to protect workers from pesticide exposure, to regulate the distribution of pesticides and their applications, and to harmonize existing regulations among pesticide exporting and importing countries are also discussed. The possibilities of developing a regional framework and database to regulate pesticides for countries from the same region are explored.

Chapter 4 highlights different policies to manage pesticide use and the consequences of disorganized pesticide practice on diverse environmental components. Different pest control strategies are briefly discussed. Proper use of pesticides is required to protect the environment and reduce health risks associated with pesticide use.

Chapter 5 presents an overview of chemical, biological, and photo-degradation of pesticides and their environmental concerns. The key technical challenges and prospects to identify the pathways of pesticide degradation are briefly discussed.

Chapter 6 reviews modes of exposure to pesticides and pesticide residues and possible acute and chronic effects of pesticides on human health. Intentional or unintentional exposure to pesticides and pesticide residues may cause cancer, skin diseases, visual disturbance, chronic deterioration in neurologic function, paralysis, reproductive effects, and neurologic effects. Different approaches to prevent irrational use of pesticides, and hence the need of avoiding associated health issues, are discussed.

Chapter 7 highlights different food processing techniques as well as post-harvest treatments to reduce pesticide residues in foods. Effects of food washing, cooking, brewing, and storing on the dissipation of pesticide residues in foods are briefly discussed.

Chapter 8 presents different analytical techniques for the qualitative and quantitative detection of pesticides and pesticides residues in foods. The analytical methods include extraction and cleanup of the target analytes from the food samples and determination of the target analytes.

Chapter 9 outlines different alternative tactics of pest management, which include cultural control, physical and mechanical control, biological alternatives,

and integrated pest management. The ecological and health impacts, limiting factors, market trend, and future prospects of biopesticides and other alternative approaches were briefly discussed.

Chapter 10 analyzes recent developments and future prospects of organic farming as an effective technique to reduce pesticide use. The critical factors of organic farming, such as yield reduction, soil fertility, integration of livestock, certification, ecology, marketing, and policy support, were analyzed. The economic, health, and ecological benefits associated with organic farming are also highlighted.

The readers of this book will be the upper-level undergraduate and graduate students, researchers, academics, and engineers working in different aspects of the food safety in relation to their contaminants. In addition, professionals working in the food regulatory authorities will find this book as an informative source. We are confident that the readers will find this book informative and enlightening.

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Introduction

Mohidus Samad Khan and Mohammad Shafiur Rahman

Globally, there is a growing concern of the improper use of pesticides in the agricultural sector. The probable detrimental effects of pesticides to human health and environment are the key reasons of this concern. In this book, the sources of pesticide residues in foods, analytical techniques for the qualitative and quantitative detection of pesticides in foods, relevant health and environmental concerns, degradation of pesticides after their use, and available laws and regulations to regulate pesticide use are discussed. In addition, different pesticide management techniques, such as: reduction of pesticide residues in grains and foods, alternatives to conventional pesticides, and prospects of organic farming are also covered.

1 What Are Pesticides?

Pesticides are the substances or mixture of substances used to prevent, destroy, or control pests that may cause harm during production, processing, storage, transport, or marketing of foods and other agricultural commodities [1]. Pesticides are broad term that includes insecticides, herbicides, fungicides, rodenticides, miticides, and other growth regulators. The key objectives to use pesticides are to control pests and plant diseases, to control organisms that could harm human activities and structures (such as: wooden structures), to improve yield and quality of crops, and to save production cost of agricultural products [2, 3]. Pesticides helps farmers and consumers by ensuring vast quantities of quality produce available year-round [2].

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Globally, pesticide production, distribution and application is a billion dollar industry, which also provides job opportunities to millions of people around the world [4, 5]. However, the effects of pesticides and pesticide residues could be non-selective to pests and other living organisms, and may contaminate waterways, impact non-target and beneficial organisms, and persist in the environment for years. Pesticide residues can be found in foods. Improper use of pesticides and existence of pesticide residues in foods may be detrimental to human health. Therefore, it is important to know their complete knowledge including risk-benefit analysis for humans and environment.

2 Historical Background of Pesticide

The history of using pesticides to control pests is more than 4000 years old. It is reported that different elemental compounds, such as sulphur, mercury, lead, arsenic and copper containing compounds had been used as pesticides to control insect pests [6]. The scopes and applications of pesticides have been increased over the centuries to meet the high yield and the demand of defect free food production [7]. Worldwide, synthetic chemicals have been extensively used for the last few decades to inhibit or control pests, insects, diseases, weeds, and other pathogens to diminish or remove yield losses and uphold high quality product. In recent years, the market of alternative pesticides, such as biopesticides, is also growing to reduce pesticide related health and environmental hazards.

3 Pesticide Residues in Foods

Pesticides can be classified according to their chemical structures, working principles, target molecules, and possible health effects. Considering the above factors, pesticides can be broadly classified as organochlorine pesticides, organophosphorous pesticides, carbamates, pyrethroids pesticides, biorational pesticides, and microbial pesticides [8]. These chemical substances are often persistent. Because of the irrational use of pesticides during cultivation pesticide residues can be found in crops, soils and waterways [9]. Different analytical methods, such as: various extraction, chromatographic and spectrophotometric techniques, play an important role for the detection of pesticide residues in foods.

4 Health and Environmental Impact of Pesticide Residues in Foods

Pesticides are often developed to function with minimal risk to human health and the environment; however, different scientific studies have raised concerns about health risks from occupational and non-occupational exposures to pesticides and pesticide residues [10]. Pesticides have been linked to a number of health problems,

including neurologic and endocrine (hormone) system disorders, birth defects, and cancer [11]. The health effects of pesticides vary according to exposure time, individual health condition, and the chemical toxicity of pesticides [10]. It is important to identify and measure the harmful effects (i.e. complete risk assessment) of pesticides on human health. While determining the effects of pesticides on human body, it is necessary to consider certain key factors including route of exposure, dosing rates, chemical structure, absorption characteristics, types of pesticides and metabolites, and individual health condition [12].

5 Laws and Regulations of Pesticides

Pesticide use is growing all over the world; therefore, many countries are looking for ways to permit people to experience the advantages of chemical pesticides without being endangered to their use. There are growing concerns among stakeholders to ensure the access of relevant information on pesticides. Many countries have developed laws and regulations to regulate pesticide production, sales, and applications [13–29]. However, because of the lack of necessary infrastructure, some countries rely only on information, such as labelling, application rates, usage patterns, material safety data sheets, and in-house summaries of toxicity studies, provided by international manufacturers. There are international codes of conducts and conventions to promote shared responsibilities and cooperative efforts among parties [30–32]. These international conventions and codes also offer strategies to protect workers from pesticide exposure, to regulate the distribution of pesticides and their applications, and to harmonize existing regulations among pesticide exporting and importing countries. Developing regional framework and database could be effective in regulating pesticides for countries from the same region. Implementation of existing and new laws and regulations is the other key factor for ensuring proper regulation of pesticides.

6 Management of Pesticide Handling and Use

Because of health and environmental hazards, worldwide pest management is facing economic and ecological challenges [33]. To overcome these challenges, regulatory actions have been taken by regulatory and environmental protection agencies of different nations. The manufacturer or the formulator along with the national authority should ensure proper labelling written in local language with warning of possible hazards and comprehensive instructions for safe use. The users and producers should use personal protective equipment to prevent the risk of personal hazard [34]. In any pesticide poisoning, the first thing to do is avoiding further contamination, and ensuring that the victim is breathing so that proper oxygen supply to the body can be maintained. Following this, medical assistance should be sought [35].

7 Methods of Pesticide Analysis

Proper analytical tools and techniques are necessary to determine pesticide contents in foods and environment. Qualitative and quantitative detection of pesticide residues in foods and environment involves sophisticated analytical techniques and multiple experimental steps [36–39]. Measuring pesticides in foods and environment include sample preparation followed by extraction and clean-up of target analytes from the sample, and chromatographic and/or spectrophotometric detection of the isolated target analytes. Multi-residue analytical methods can be used for the simultaneous detection of different analytes in a single run [40].

8 Alternative Pesticides and Organic Farming

Increased understanding and awareness of the adverse effects of pesticides on health and environment is driving the demand for alternatives of pesticides. The alternative approaches consider pest problems within a broad context, which include the presence of natural enemies, the distribution of pest population, active season to grow, and expected weather patterns [41–43]. Biopesticides can be a replacement of synthetic chemical pesticides; biopesticides poses lower risk to the environment and human health [44, 45]. Many sustainable farms use Integrated Pest Management (IPM) as an alternative to pesticides [46, 47]. The overall optimization of pesticide handling by following the existing regulations could contribute to the reduction of the adverse effects of pesticides on human health and the environment [48].

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Sources of Pesticide Residues in Food: Toxicity, Exposure, and Risk Associated with Use at the Farm Level

Michael L. Deadman

1 Introduction

The contribution of pesticides towards substantial increases in global crop yields during the twentieth century is well understood and has been well documented (see for example, [10]). The so-called Green Revolution of the 1940s–1960s was fuelled by the development of high-yielding crop varieties, the expansion of updated irrigation technologies and the more widespread use of agrochemicals, including synthetic products, for the control of pests and diseases. This sea change in food production methodology is credited with saving the lives of many millions of rural poor in less developed countries and with raising living standards globally. The increasing dependency on, and deployment of, pesticides in crop production that followed the Green Revolution gave birth to an environmental backlash that found voice in Rachel Carson’s book *Silent Spring* (1962). In her book, the author describes a natural environment under threat from the increasing use of agrochemicals; an environment quietened, with bird populations silenced as a result of feeding on insects contaminated by toxic chemicals. Heightened environmental awareness within the general public in developed countries, and increasingly so in less developed countries, has encouraged policy makers to respond with increasingly stringent regulatory management of pesticide deployments. Indeed, in many countries environmental campaigners, through non-governmental organizations (NGOs) have now gained admission to bodies involved in policy development. Furthermore, there is an increasing corpus of internationalized “legislation” with the formulation of a suite of conventions seeking to limit the movement and use of certain pesticides. Nonetheless, problems remain for food producers in developed, especially less developed countries. The issue of risk from pesticide residues fundamentally arises

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from the twin concerns of pesticide toxicity and the hazard it represents, and exposure to these hazards in the environment or in food. Toxicity hazards are related to the intrinsic chemicals (i.e. active ingredients) and so-called inert components of pesticides. Active and other pesticide ingredients have quantifiable toxicities to fish, mammals, bees and humans: they have measurable acute (short term) and chronic (long-term) toxicities. Exposure, *per se*, to a hazardous pesticide is a function of the amount of the chemical in an environment (soil, water or food for example), which is related to that chemical's mobility, persistence and half-life. The food-based residues exposed are related to the intake of specific food items. Of concern to those involved in crop production at the farm level is the exposure route. In other words, it becomes an issue of how the environmental or food load can be minimized using good agricultural practice (GAP). Pesticide loads in the environment or in food are related to the cropping industry's ability to diagnose and quantify a problem and to select an appropriate chemical management solution. The load is also affected by compliance with recommended pesticide dosages and the correct use of appropriate equipment for pesticide application. Load will rise in response to a cavalier approach to the use of personal protective equipment by farm workers, and poor compliance with recommended waiting periods between pesticide application and harvest. Such multifarious elements of the risk quotient are difficult to assess and few attempts have been made to quantify their impact across regions or on downstream sectors of the food industry. In essence, toxicity level and degree of exposure are largely governed by policy; the environmental or food load that leads to exposure is a product of the efficacious implementation of these policies.

2 A Brief History of Pesticides

Although for the public at large the word pesticide is frequently used pejoratively, this is a recent phenomenon. For the vast majority of the history of pesticide use, their character has been seen as benign, positively beneficial. That history is a long one - pesticide use in agriculture goes back several thousand years. Elemental sulphur was used as a dust in Mesopotamia around 2500 BC. In the fifteenth century compounds of mercury, lead and arsenic were being used on crops to fight infestations of insect pests. Indeed, arsenic and mercury containing pesticides remained widely used well into the twentieth century. The nineteenth century saw the emergence of copper containing compounds for the management of fungal diseases. Bordeaux mixture was invented in 1885 as a mixture of copper sulphate and lime. It was as an effective management option for the control of the increasingly damaging vine downy mildew problem and the application of elemental sulphur to the plant surface was difficult to control [28]. Bordeaux mixture and elemental sulphur are still widely used in modern agriculture.

The emergence of chlorine-containing compounds as pesticides was heralded by the synthesis of DDT in 1874 and the subsequent recognition, by Paul Müller in 1939, of its insecticidal properties (for which Müller received a Nobel Prize).

After World War II the use of DDT use in agriculture increased dramatically and an age of organochlorine dominance was established that lasted until the 1970s. After that organophosphate and carbamate insecticides began to replace the chlorine compounds, which was identified for the increasingly serious environmental damage Rachel Carson railed against in *Silent Spring*.

In *Silent Spring* [8], Carson critically examines the use of pesticides in controlling insects and the effects of organochlorine and organophosphate pesticides on the broad spectrum of life, including wildlife and indeed, humans. Carson emphasized that the public has a right to know the effects of these chemicals to human health and the environment before their exposure. In the concluding paragraph, Carson says “control of nature is a phrase conceived in arrogance, born of the Neanderthal age of biology and philosophy, when it was supposed that nature exists for the convenience of man. The concepts and practices of applied entomology for the most part date from that Stone Age of science. It is our alarming misfortune that so primitive a science has armed itself with the most modern and terrible weapons, and that in turning them against the insects it has also turned them against the earth” [8].

Recent decades have seen the emergence of systemic pesticides, which has the ability to move within plants. Pesticides such as sulphur, copper sulphate and organo-metal compounds owe their activity to the ability to adhere to the surface of plants to provide a protective coat that repels, through toxicity as it were, the attacking insect or fungus. Systemic pesticides in contrast, are absorbed by the plant and carried through the vascular system. Most systemic pesticides are carried through the xylem, or water conducting vessels of the plant; relatively fewer are phloem transported.

The modes of action of pesticides are as varied as their chemistries. Early organochlorine and organophosphate insecticides were neurotoxins with either very long persistence (some organochlorines) or with extreme toxicity (some organophosphates) [34]. Later developed insecticides also include those with neurotoxicological modes of action (pyrethroids), those that block the enzyme acetylcholinesterase (carbamates), those that act as agonists to acetylcholine (neonicotinoids) and those that mimic the action of insect hormones [34, 51]. Fungicides, like insecticides have a diversity of modes of action. Many act through a disruption of fungal membrane function such as sterol or glycerophospholipid biosynthesis inhibitors, others have effects on cell wall function, inhibit protein synthesis, inhibit respiration or inhibit calcium (Ca^{2+}) signalling [28].

In the years that have followed the publication of *Silent Spring*, there is no doubt that emphasis at national and international levels has been increased on the reduction of risks associated with pesticide use. Greater efforts have been placed both on the reduction of the toxicological hazards (i.e. limiting exposure via environment and dietary intake) of the active ingredients, which are available in agricultural use. Since 1991 the EU, for example, has withdrawn the registration status of several 100 pesticide active ingredients (<http://eur-lex.europa.eu>), although as we'll see, the actual number of active, active ingredients withdrawn is a point for debate. Many countries routinely review the safety data relating to pesticides and periodically proscribe additional active ingredients. The Sultanate of Oman, for example, on the grounds of environmental and human safety, recently enacted legislation to prohibit

the use of 131 pesticide active ingredients and restrict the use of a further 30 [3]. In addition to national legislation (or lack thereof) most nations are signatories to international conventions. The Stockholm Convention prohibits the production and use of certain persistent organic pollutants (POPs), including pesticides (Table 1). Similarly, the Rotterdam Convention imposes limitations to the transboundary shipment of certain pesticide active ingredients without prior informed consent (Table 2).

Semantics are important in order to avoid confusion. Because those contributing to the scientific literature relating to pesticides are prone to the use of loose, or poorly defined terminology and the overlapping use of words with similar meanings, it is worthwhile here to introduce some definitions of terms that will be used throughout the rest of the chapter. So, a toxin is a poison; a chemical that is poisonous is a chemical that has toxicity and is capable of causing damage to living things or to the environment. To be exposed is to be open to danger; exposure therefore is the state of having no protection from a danger (or hazard). Finally, a risk is the possibility (or here, mathematical probability) of something (usually unpleasant) happening. Other terms will also crop up here, especially a key component of a novel concept in pesticide risk assessment. So, a hazard is a danger; a hazardous chemical is a chemical that represents a danger, perhaps because of its toxicity. An impact is a marked effect (i.e. degree of damage) or influence.

3 Pesticide Toxicity and Hazard

Pesticides are chemicals (or usually cocktails of different chemicals packaged together for sale). Therefore, each of the ingredients of a pesticide has specific properties - molecular weight, solubility, boiling point, and so on. Chemical pesticides usually consist of two types of ingredients: an active ingredient (sometimes more than one “*ai*” or just “active”) that has specific properties making them effective in (usually) killing a target, such as an insect, fungus or weed. The active ingredient of a pesticide may make up less than 50% of the formulated product; sometimes much less than 50%. The remaining contents are usually composed of a mixture of ingredients including perhaps solvents, chemicals that help the *ai* to stick to the plant surface, or chemicals that protect the *ai* from photo-degradation, etc. These non-*ai* ingredients are referred to “inert ingredients” or sometimes simply “inerts”, although as we shall see, these so-called inert ingredients are frequently far from inert. All chemical ingredients in a pesticide also have a taxonomy and are classified accordingly; each one has a unique identification code such as the CAS (Chemical Abstract Service) identifier number (www.cas.org). The widely used insecticide active ingredient Avermectin (Abamectin), for example, has the CAS numbers 65195-55-3 and 65195-56-4 for the B1A, B1B forms (different from each other as shown by R in Fig. 1) and 71751-41-2 for the mixture of the B1A and B1B forms. Avermectin, a naturally occurring product from the fermentation of the actinomycete *Streptomyces avermitilis*, is placed within the group of chemicals known as macrocyclic lactones, referring to the basic structure of the molecule:

Table 1 Pesticides covered by the Stockholm Convention on Persistent Organic Pollutants (POPs)

Pesticide included in the original Convention document, coming into force in 2004	CAS number	Chemical group and target	Additional POP pesticides added in 2009 or under consideration for future inclusion	CAS number	Chemical group and target
Aldrin	309-00-2	Organochlorine herbicide	Alpha hexachlorocyclohexane	319-84-6	Organochlorine insecticide
Chlordane	57-74-9	Organochlorine insecticide	Beta hexachlorocyclohexane	319-85-7	Organochlorine insecticide
DDT	50-29-3	Organochlorine insecticide	Chlordecone	143-50-0	Organochlorine insecticide and fungicide
Dieldrin	60-57-1	Organochlorine insecticide	Hexachlorobutadiene	87-68-3	Organochlorine herbicide
Heptachlor	76-44-8	Organochlorine insecticide	Lindane	58-89-9	Organochlorine insecticide and acaricide
Hexachlorobenzene	118-74-1	Organochlorine fungicide	Pentachlorobenzene	608-93-5	Organochlorine fungicide
Mirex	2385-85-5	Organochlorine insecticide	Endosulfan ^a	115-29-7	Organochlorine insecticide and acaricide
Toxaphene	8001-35-2	Organochlorine insecticide	Dicofol ^b	115-32-2	Organochlorine acaricide

Adapted from: www.chm.pops.int; Stockholm Convention [48]

^aEndosulfan is included but with specific exemptions of use

^bDicofol is currently under consideration for inclusion

Table 2 Pesticides subject to the Rotterdam Convention on the Prior Informed Consent for the transboundary movement of hazardous chemicals and pesticides in international trade

Pesticide	CAS number	Chemical group and target	Pesticide	CAS number	Chemical group and target
2,4,5-T and its salts and ester	93-76-5	Synthetic auxin fungicide and herbicide	Ethylene oxide	75-21-8	Cyclic ether fumigant
Alachlor	15972-60-8	Chloroacetamide herbicide	Fluoroacetamide	640-19-7	Acetamide rodenticide and insecticide
Aldicarb	1116-06-3	Carbamate insecticide, acaricide and nematocide	HCH (mixed isomers)	608-73-1	Organochlorine insecticide
Aldrin ^a	309-00-2	Organochlorine herbicide	Heptachlor ^a	76-44-8	Organochlorine insecticide
Azinphos-methyl	86-50-0	Organophosphate insecticide, acaricide and molluscicide	Hexachlorobenzene ^a	118-74-1	Organochlorine fungicide
Binapaeryl	485-31-4	Dinitrophenol fungicide, insecticide and acaricide	Lindane (gamma-HCH) ^a	58-89-9	Organochlorine insecticide and acaricide
Captafol	2425-06-1	Phthalimide fungicide	Mercury compounds, including inorganic mercury compounds, alkyl mercury compounds and alkyloxyalkyl and aryl mercury compounds	Various	Fungicide and insecticide
Chlordane ^a	57-74-9	Organochlorine insecticide	Methamidophos	10265-92-6	Organophosphate insecticide and acaricide
Chlordimeform	6164-98-3	Formamidine acaricide and insecticide	Monocrotophos	6923-22-4	Organophosphate insecticide and acaricide
Chlorobenzilate	510-15-6	Organochlorine acaricide and insecticide	Parathion	56-38-2	Organophosphate insecticide and acaricide
DDT ^a	50-29-3	Organochlorine insecticide	Pentachlorophenol and its salts and esters	87-86-5 (* ^a)	Organochlorine insecticide, herbicide, fungicide, molluscicide, plant growth regulator and wood preservative

Dinitro-ortho-cresol (DNOC) and its salts (such as ammonium salt, potassium salt and sodium salt)	534-52-1	Dinitrophenol herbicide, insecticide, acaricide and fungicide	Tributyl tin compounds	1461-22-9, 1983-10-4, 2155-70-6, 24124-25-2, 4342-36-3, 56-35-9, 85409-17-2	Organometal fungicide and molluscicide
Dinoseb and its salts and esters	88-85-7 (*)	Dinitrophenol herbicide	Dustable powder formulations containing a combination of benomyl at or above 7%, carbofuran at or above 10% and thiram at or above 15%	137-26-8, 1563-66-2, 17804-35-2	Benomyl – Benzimidazole fungicide and acaricide; Carbofuran – Carbamate insecticide, acaricide and nematocide; Thiram – Carbamate fungicide
EDB (1,2-dibromoethane)	106-93-4	Organobromine fumigant and insecticide	Methyl-parathion (Emulsifiable concentrates (EC) at or above 19.5% active ingredient and dusts at or above 1.5% active ingredient)	298-00-0	Organophosphate insecticide and acaricide
Endosulfan ^a	115-29-7	Organochlorine insecticide and acaricide	Phosphamidon (Soluble liquid formulations of the substance that exceed 1000 g active ingredient/l)	13171-21-6	Organophosphate insecticide and acaricide
Ethylene dichloride	107-06-2	Chlorinated hydrocarbon insecticide			

Chemical groups according to *PPDB* Pesticide Properties DataBase (sitem.herts.ac.uk/aeru/ppdb/en/index.htm)

Adapted from: www.pic.int, Rotterdam Convention [46]

^aPesticides also included in the Stockholm Convention, see Table 1