Mohidus Samad Khan
Mohammad Shafiur Rahman *Editors*

Pesticide Residue in Foods

Sources, Management, and Control

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Editors
Mohidus Samad Khan
Department of Chemical Engineering
Bangladesh University of Engineering and Technology
Dhaka, Bangladesh

Mohammad Shafiur Rahman
Department of Food Science and Nutrition
Sultan Qaboos University College of Agricultural Marine Sciences
Muscat, Oman

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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.

Dhaka, Bangladesh Mohidus Samad Khan
Muscat, Oman Mohammad Shafiur Rahman

Contents

Introduction

Mohidus Samad Khan and Mohammad Shafiur Rahman

Globally, there is a growing concern of the improper use of peptides 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].

M.S. Khan (✉)
Department of Chemical Engineering, Bangladesh University of Engineering and Technology (BUET), Dhaka 1000, Bangladesh
e-mail: mohid@buet.ac.bd

M.S. Rahman
Sultan Qaboos University, Muscat, Oman
e-mail: Shafiur@squ.edu.om

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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 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, pyrithroids 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

M.L. Deadman (✉)
Department of Crop Sciences, Sultan Qaboos University, Muscat, Sultanate of Oman
e-mail: mikedead@squ.edu.om

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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 organometal 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]
[a]Endosulfan is included but with specific exemptions of use
[b]Dicofol is currently under consideration for inclusion

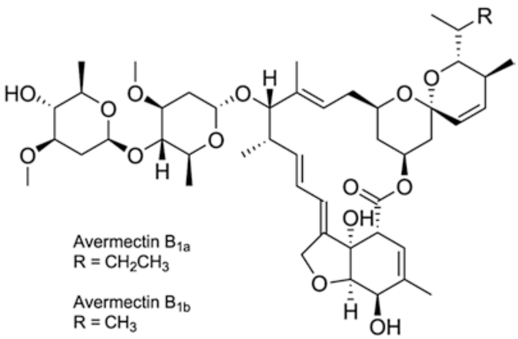
Table 2 Pesticides subject to the Rotterdam Convention on the Prior Informed Content for the transboundary movement of hazardous chemicals and pesticides in international trade

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	116-06-3	Carbamate insecticide, acaricide and nematicide	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
Binapacryl	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 (*)	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 nematicide; 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]
[a]Pesticides also included in the Stockholm Convention, see Table 1

Fig. 1 Chemical structure of Avermectin



General information about the hazardous nature of a specific chemical pesticide and the risks associated with its use are included in the Material Safety Data Sheet (MSDS). In many countries, the information on the MSDS (and the product label) are approved by the relevant national regulatory body, such as the US Environmental Protection Agency (EPA), and the MSDS thus becomes the legal mechanism of approved rates and uses is given [50]. A typical MSDS also provides information about the toxicology of the pesticide. In the case of Avermectin, this information includes details about oral and dermal toxicities (usually reported as an LD_{50} value), inhalation toxicity (as LC_{50}) and skin and eye irritation potential (Table 3). All data is collected from laboratory-based experiments involving small animals.

The MSDS also contains information about the chronic toxicity of pesticides where this is available. This will include any known carcinogenicity reports as well as details of specific target organ effects (eyes, skin, liver, kidneys, central nervous system, and respiratory system), effects on reproduction and development (endocrine effects) and any known genotoxicities. Ecological information is provided in the form of LD_{50} or LC_{50} concentrations used on key indicator species of fish, birds and invertebrates including bees. Environmental fate is usually reported as chemical half-life in soil and in water (Table 3).

Many attempts have been made to bring together the available data on the hazards posed by a specific pesticide. Amongst the most widely referenced is that produced by the World Health Organization [60]. In 2009, WHO revised their criteria for the classification of pesticides based on Acute Toxicity Hazard Categories from experimental data to determine the rat LD_{50} (mg/kg) via the oral and dermal routes (Table 4).

The WHO classification of pesticides, naturally, places the toxicological emphasis on the potential impact of a chemical pesticide on mammalian health. Of course, broader concerns also need to be addressed, including the potential environmental hazard. The Pesticide Action Network (PAN, www.pesticideinfo.org), an international coalition of non-governmental organizations (NGOs) and others that campaigns against the excessive use of pesticides, maintains a database of pesticide active ingredients and their hazards. The PAN database provides toxicology summary information, gleaned from a variety of sources, and summarized as five indicators of hazardousness: acute toxicity, carcinogenicity, cholinesterase inhibition,

Table 3 Toxicological and environmental hazard data for the insecticide Avermectin as provided by the Material Safety Data Sheet (MSDS)[a]

Test	Subject[b]	Result
Oral	Rabbit LD_{50}	300 mg/kg
Dermal	Rat LD_{50}	>5000 mg/kg
Inhalation	Rat 4-h LC_{50}	>2.09 mg/L
Eye irritation	Rabbit	Moderately irritating
Skin irritation	Rabbit	Slightly irritating
Skin sensitization	Not a contact sensitizer in guinea pigs following repeated skin exposure	
Ecotoxicity	Bluegill 96-h LC_{50}	9.6 ppb
	Rainbow trout 96-h LC_{50}	3.6 ppb
	Daphnia 48-h EC_{50}	0.34 ppb
	Honey bee 48-h contact LD_{50}	0.022 μg/bee
	Bobwhite quail oral LD_{50}	>2000 mg/kg
	Bobwhite quail 8-day dietary LC_{50}	3102 ppm
	Mallard duck 5-day dietary LC_{50}	383 ppm
Environmental fate	Average half-life in soil	5–10 h
	Average half-life in water	18 h

[a]Nufarm Abamectin 0.15 EC Insecticide MSDS, issued October 1, 2010

[b]LD_{50}: The median lethal dose is the average amount of a chemical substance capable of killing 50% of the test animals exposed under specific experimental conditions; usually expressed in mg/kg body weight by oral intake or skin exposure; LC_{50}: The median lethal concentration is the average concentration of a chemical as gas, vapour, mist, fume or dust capable of killing 50% of the test animals exposed by inhalation under specific experimental conditions; often expressed as mg/L over a given time of exposure; EC_{50}: The half maximal effective concentration (EC_{50}) is the concentration of a pesticide which induces a response halfway between the baseline and maximum after a specified exposure time.

Table 4 World Health Organization Acute Toxicity Hazard Categories for the classification of pesticide active ingredients

WHO Class		LD_{50} for the rat (mg/kg body weight)		Example active ingredients
		Oral	Dermal	
Ia	Extremely hazardous	< 5	< 50	Captafol
Ib	Highly hazardous	5–50	50–200	Beta-cyfluthrin
II	Moderately hazardous	50–2000	200–2000	Lambda cyhalothrin Endosulfan
III	Slightly hazardous	Over 2000	Over 2000	Hexaconazole
U	Unlikely to present acute hazard	5000 or higher		Mancozeb

reproductive or developmental toxicity, endocrine disruption and potential of the active ingredient to contaminate groundwater (Table 5). In addition, the PAN database labels active ingredients as “Bad Actors” if they have been shown to represent a known toxicological hazard in any one category.

The PAN classification of some widely used pesticide active ingredients is shown in Table 6. The list represent those pesticide active ingredients most extensively

Table 5 Classification system for pesticide active ingredients adopted by the Pesticide Action Network and used to categorize the toxicities of pesticides

	Acute toxicity	Carcinogen	Cholinesterase (ChE) inhibitor	Groundwater contaminant	Development or reproductive toxin	Endocrine disruptor	PAN Bad actor chemical
PAN categories	Extremely toxic	Known	Yes	Known	Yes	Suspected	Yes
	Highly toxic	Known (EPA/P65)[a]	No	Potential	No	Insufficient data	No
	Moderately toxic	Probable		Insufficient data			
	Slightly toxic	Possible					
	Not acutely toxic	Unclassifiable					
		Unlikely					
Other ranking systems with equivalences or sources of information	WHO, US EPA, US National Toxicity Program, MSDS data, US EPA's Toxic Releases Inventory	US EPA, International Agency for Research on Cancer (IARC), US National Institute for Health, State of California Proposition 65 Carcinogen List (P65)	MSDS, California Department of Pesticide Regulation's list of ChE-inhibiting pesticides	**Potential** groundwater contaminants are those that meet the California Department of Pesticide Regulation's (DPR's) criteria. **Known** groundwater contaminants either meet DPR's criteria or have been found repeatedly in groundwater in California (and elsewhere), but are not regulated as groundwater contaminants in California.	US EPA's Toxic Releases Inventory, State of California Proposition 65 List	PAN uses a combination of data sources including the llinois EPA List, Danish EPA List of Endocrine Disrupting Auxiliaries, the European Union Prioritization List, the Colborn List, the Keith List and the Benbrook List. See pesticideinfo.org for more details	Based on known toxicities in any one of the other categories

[a]Pesticide active ingredients listed as a carcinogen by US EPA and/or P65 but not by the other organizations

Table 6 Most extensively used (ha treated) active substances on vegetable crops in 2013 in the United Kingdom (excluding seed treatments) along with the PAN classifications and WHO hazard class for these active compounds

Active substance	Use type	Acute toxicity	Carcinogen	Cholinesterase inhibitor	Groundwater contaminant	Development or reproductive toxin	Endocrine disruptor	PAN Bad actor Chemical	WHO
Lambda-cyhalothrin	Insecticide	Moderate	Not likely	No	No data available	No data available	Suspected	Not listed	II
Pendimethalin	Herbicide	Slight	Possible	No	No data available	No data available	Suspected	Not listed	II
Pirimicarb	Insecticide	Moderate	Known (P65)	Yes	No data available	No data available	No data available	Yes	II
Azoxystrobin	Fungicide	Not acutely toxic	Not likely	No	Potential	No data available	No data available	Not listed	U
Mancozeb	Fungicide	Not acutely toxic	Known	No	Potential	Yes	Suspected	Yes	U
Deltamethrin	Insecticide	Moderate	Unclassifiable	No	No data available	No data available	No data available	Not listed	II
Linuron	Herbicide	Slight	Possible	No	Potential	Yes	Suspected	Yes	III
Clomazone	Herbicide	Moderate	Not likely	No	Potential	No data available	No data available	Not listed	II
Prothioconazole	Fungicide	Not acutely toxic	Not likely	No	No data available	No data available	No data available	Not listed	U
Ioxynil	Herbicide	Moderate	No data available	No	No data available	No data available	Suspected	Not listed	II

Source: Garthwaite et al. ([22], [23])

used by vegetable growers in the UK, the data is taken from the most recent series of regular surveys [23]. Although six of the ten active ingredients listed are within Class II of the WHO hazard classification, only three are listed as PAN bad actor chemicals. Herein lies an important issue in the discussion of pesticide toxicity hazard data: although the science behind the estimation of active ingredient toxicities may be precise, the interpretation of this information becomes profoundly less precise if quantitative toxicological data is first transformed into one of several qualitative layers (high, medium, and low, for example) and multiple criteria so transformed are amalgamated into complex quasi-quantitative indices or quotients of environmental or human impact. It is little wonder then that Maud et al. [36] noted a poor correlation between the rankings of pesticides, when the ranks themselves were based on toxicological data.

Problems with impact quotients will be discussed further below. An examination of similar data collected for the same crop types in the UK less than 15 years earlier, in 1999 [26], shows nine of the ten most widely used active ingredients are classed as Moderately Hazardous (Class II) and five are listed as PAN "Bad Actor" chemicals (Table 7). In part, the reduction in Class II pesticides in the top ten list is a result of the withdrawn approval, by EU regulations, of Cyanazine and Propachlor (both herbicides) in 2002 and 2008 respectively. Limitations of quotient systems notwithstanding, clearly there has been an apparent decrease in the hazard level of the most frequently used pesticides over time.

Other reports of time-wise decreases in the overall toxicity hazards represented by the suite of pesticide active ingredients available and/or used in agriculture similarly show a decrease in toxicity over time. Of the ten pesticides most widely (per hectare) used in grassland and fodder crop production in UK in 1997, nine were in WHO toxicity class Ib or II [25]. In 2013, amongst the most widely used on a hectare basis [22] only four products were in Class II with no Class Ib products.

Table 7 Most extensively used (ha treated) active substances on vegetable crops in 1999 in the United Kingdom (excluding seed treatments) along with the PAN classifications and WHO hazard class for these active compounds

Active ingredient	Use type	PAN Bad actor chemical	WHO Classification
Lambda-cyhalothrin	Insecticide	Not listed	II
Pirimicarb	Insecticide	Yes	II
Chlorothalonil	Fungicide	Yes	U
Dimethoate	Insecticide	Yes	II
Metalaxyl	Fungicide	Not listed	II
Ioxynil	Herbicide	Not listed	II
Deltamethrin	Insecticide	Not listed	II
Cypermethrin	Insecticide	Not listed	II
Cyanazine[a]	Herbicide	Yes	II
Propachlor[b]	Herbicide	Yes	II

Source: Garthwaite et al. [26]

[a]Withdrawn from EU approval through regulation 2002/2076

[b]Withdrawn from EU approval through regulation 2008/742

Interestingly in this case the Class Ib active, Methiocarb is currently still permitted under EU regulations, whilst the Class III pesticide Atrazine was withdrawn under EU regulation 2004/248. Although the toxicity range of products used in arable crop production in UK showed little change between 1998 and 2014 with five active ingredients in WHO Class II in 1998 and 2014 [21, 24], Cross and Edwards-Jones [12] reported that, for UK arable crop production between 1992 and 2002, the Environmental Impact Quotient (EIQ, see below) profile of pesticides used fell by 14%. Similarly, the pesticide load (EIQ/amount used) decreased by 15% and the pesticide load per hectare fell by 7%. Although many have questioned the utility of the EIQ system (also see below), the trend of decreasing toxicities of the pesticides used by farmers over time is likely to be correct. Across Europe, the decrease in toxicities of products used in commercial farming has undoubtedly been a result of the loss of approved status of active ingredients following the adoption of EU directives, regulations and amendments to directive 91/414/EC "Placing of Plant Protection Products on the Market Directive" (subsequently replaced by EU Regulation 1107/2009) (http://eur-lex.europa.eu) [29]. The number of actives withdrawn has been significant with Karabelas et al. [29] quoting the loss of 704 ingredients. However, many of the active ingredients withdrawn are within the higher WHO toxicity classes (Table 8). Furthermore, the high number of withdrawals is, to some extent, a reflection of good housekeeping. Many ingredients were never approved for their use in the EU and these are expunged from the system (Table 9). Indeed, obsolete active ingredients make up over 25% of the products listed by the EU for withdrawal of approved status.

Table 9 also shows that the list of active ingredients with approved status withdrawn is dominated by organophosphates. Organophosphates are powerfully insecticidal, they breakdown rapidly, but are amongst the most toxic of pesticides to vertebrates, including mammals [51]. Elsewhere, Al Zadjali et al. [3] reported a temporal decrease in the overall toxicity levels of pesticides being used in Oman, between 1999 and 2012. Again, this was in response to specific legislation enacted to withdraw from the market specific active ingredients with high toxicities or with other potentially detrimental effects to the environment. Not unexpectedly, the

Table 8 Breakdown by percentage of those pesticide active ingredients with approved status withdrawn following Directive EU/1107/2009

WHO Toxicity Class	Percentage of active ingredients with EU approval withdrawn[a]
Class Ia	4.9
Class Ib	10.9
Class II	27.5
Class III	12.3
Class U	16.9
Obsolete	27.5

[a]Percentages are derived from active ingredients appearing both on the EU list of approved products (ec.europa.eu/food/plant/pesticides/eu-pesticides-database, accessed 7 November 2015) and WHO [60]

Table 9 Chemical group and principal target of pesticide active ingredients with EU approved status withdrawn

WHO pesticide classification	Chemical family	Principal target[a]							
Obsolete pesticides		AC	FU	HB	IN	NE	RO	ST	Total
	Anilide			1					1
	Aryloxyphenoxy-propionate			2					2
	Benzimidazole		1						1
	Bridged diphenyl	3			1				4
	Coumarin						1		1
	Dinitroaniline			2					2
	Organochlorine	3			2			1	6
	Organophosphate		1		22	2			25
	Oxazole		1						1
	Phenylurea			2					2
	Thiocarbamate		1	3					4
	Triazine			1					1
Toxicity class Ia									
	Coumarin						2		2
	Organophosphate				10				10
Toxicity class Ib									
	Coumarin						2		2
	Dinitrophenol			1	1				2
	Organochlorine			1					1
	Organophosphate	1			17				18
	Pyrethroid				2				2
Toxicity class II									
	Anilide			1					1
	Aryloxyphenoxy-propionate			2					2
	Chloroacetamide			3					3
	Dinitroaniline			1					1
	Dinitrophenol	1	1						2
	Organochlorine	1		1	2				4
	Organometal	2	2	1					5
	Organophosphate	1	1	1	16				19
	Oxazole			1					1
	Pyrethroid				7				7
	Thiocarbamate			5	1				6
	Triazine			1					1
Toxicity class III									
	Benzoylurea				1				1
	Chloroacetamide			3					3

(continued)

Table 9 (continued)

WHO pesticide classification	Chemical family	Principal target[a]							
	Chlorophenyl		1						1
	Dinitroaniline			1					1
	Organometal	1							1
	Organophosphate			1	2				3
	Pyrethroid				1				1
	Sulfonylurea			1					1
	Thiocarbamate			3					3
Toxicity class U									
	Anilide			1					1
	Benzimidazole		2						2
	Benzoylurea	1			3				4
	Bridged diphenyl	1							1
	Chloroacetamide			1					1
	Chlorophenyl		2						2
	Dinitroaniline			2					2
	Organochlorine			1	1				2
	Oxazole		1						1
	Phenylurea			1					1
	Pyrethroid				3				3
	Sulfonylurea			3					3
	Thiocarbamate			1					1
	Triazine			2					2

[a]*AC* acaricide, *FU* fungicide, *HB* herbicide, *IN* insecticide, *NE* nematicide, *RO* rodenticide, *ST* sterilant

overall level of the toxicities of pesticides used by farmers has also been reported to change in response to factors such as education and farmer extension programmes [47] and membership of a farmer cooperative [3].

In order to summarize the combined human and environmental hazard of pesticide active ingredients, several attempts have been made to create composite indices of pesticide impact. Amongst the first attempts at summarizing the environmental and human hazards posed by individual chemical pesticides into a single value was the Environmental Impact Quotient (EIQ) developed at Cornell in the 1990s [31]. The EIQ of a pesticide is calculated as the average of three components that assess the farm worker, consumer, and ecological hazard components. The formula used includes measures of dermal and chronic toxicity, active ingredient systemicity, fish, bee, bird and beneficial arthropod toxicity, leaching and plant surface life potential, and soil and plant surface half-life. Even though many alternative and in most cases, more complex and realistic evaluation models have been developed since the EIQ, it remains the most widely used. This is arguably because of its simplicity and because an updated database is available that holds the EIQ scores of many pesticides. This makes it a simple and tempting tool that provides a single value for the "impact" of a pesticide active ingredient. Many published reports have incorporated an evaluation of pesticide use based on EIQ changes or differences between seasons [37], over time [47], across crop types [20], when transgenic and conventional crops are compared [7, 30], and between farmers [5].

There have been many powerful critiques of the EIQ methodology, especially since its later refinement to include data on field application rates for pesticides. Essentially, the problem lies with the fact that the EIQ system and similar schemes use qualitative labels to estimate risks to the worker, consumer and environment. The EIQ equation incorporates arbitrary qualitative ratings (1, 3 and 5 for low medium and high risk/impact/toxicity/persistence) into a mathematical function as absolute certainty values without reference to probability of occurrence [43]. By way of providing an example of the discrepancies thrown up when uncertainty (probability associated with risk) is explicitly excluded, Peterson and Schleier III [43] cite the examples of cypermethrin and acetamiprid (both insecticides) with EIQ ratings of 36.4 and 28.7 respectively (ie potentially large differences environmental impact). When uncertainty is incorporated the adjusted EIQ values for the two insecticides overlap with each other for more than 90% of their ranges. Peterson and Schleier III [43] argue that instead of qualitative schemes there is a need for alternatives that quantitatively estimate risk through the integration of toxicity and exposure information. Increasingly so, this probabilistic approach is becoming more widely adopted by regulatory agencies and academics. Other concerns about the use of EIQ arise from the difficulty in coping with the increasingly frequent use of pesticide mixtures. The multiplication of an EIQ value by a number of pesticide applications (thereby multiplying the error) [47] and the frequent use of surrogate EIQ scores where the Cornell database does not include an EIQ rating for a specific active ingredient. Such surrogates are frequently calculated from averages of other pesticides within the same class of actives [12, 13, 32]. Alternatives to the EIQ method, using probabilistic analyses, to assess risk as a function of toxicity and exposure are further discussed below.

In any discussion of toxicology, hazard and exposure, the emerging concern surrounding the so-called inert ingredients within pesticide formulations needs to be mentioned. By definition, all pesticide formulations contain at least one (frequently two, occasionally more than two) active ingredients; this (these) may make up less than 50% of the contents of the pesticide container. Inert ingredients may be solvents, food substances (edible oils, spices) or other natural materials such as cellulose. Inert ingredients can play a crucial role in pesticide effectiveness (Table 10). However, "inert" is not synonymous with "non-toxic" and many countries require regulatory approval and a review of safety information of inert ingredients before products containing them can enter the market. Nonetheless, the precise formulation of inert ingredients is frequently a trade secret and argument has raged over whether full public disclosure of inert ingredients should be required [59].

Research suggests that inert ingredients within pesticide formulations can increase the ability of pesticide formulations to alter toxicological outcomes

Table 10 Possible functions of inert ingredients within pesticide formulations

Sl. No.	Function
1	Act as a solvent to help the active ingredient penetrate a plant's leaf surface
2	Improve the ease of application by preventing caking or foaming
3	Extend the product's shelf-life
4	Improve safety for the applicator
5	Protect the pesticide from degradation due to exposure to sunlight

Source: www2.epa.gov/ingredients-used-pesticide-products

Table 11 Comparison of groundwater ubiquity scores for four active ingredients and some of the inert ingredients with which they may be formulated

Name	Koc[a]	Soil half-life (days)	GUS[a] score	GUS designation[b]
Glyphosate	**24,000**	**30**	**-0.56**	**Nonleacher**
1,2-benzisothiazolin-3-one	104	30	2.93	Leacher
POEA	2500–9600	42	0.98	Nonleacher
Imazapyr	**100**	**90**	**3.91**	**Leacher**
Isopropylamine	33	20–200	4.96	Leacher
2,4-D	**53**	**7**	**2.18**	**Transitional**
Butoxyethanol	67	7–28	2.49	Transitional
Alachlor	**161**	**14**	**2.06**	**Transitional**
Chlorobenzene	126	35	2.93	Leacher

Source: Surgan et al. [49]
Active ingredients designated in bold type
[a]*Koc* carbon adsorptivity, *GUS* groundwater ubiquity score
[b]"Leacher" (GUS > 2.8), "Transitional" (GUS 1.8–2.8), and "Nonleacher" (GUS < 1.8) are used as defined by Gustafson [27]

(developmental neurotoxicity, genotoxicity, and hormone function). They can also increase exposure to pesticide active ingredients by increasing dermal absorption, decreasing the efficacy of protective clothing and increasing environmental mobility and persistence. Inert ingredients may also increase the phytotoxicity of pesticide formulations as well as toxicity to fish, amphibians, and microorganisms [6, 11]. In some cases, the inert ingredients have a greater propensity to contaminate groundwater than the actives with which they are co-formulated as indicated by higher GUS (Groundwater Ubiquity) scores ([49], Table 11). The GUS scores are a function of carbon adsorptivity (KOC) and soil half-life (DT50) of the chemicals assessed [27].

As if to emphasise the point that so-called inert ingredients can actually be anything but inert, the US EPA recently proposed the removal of 72 inert compounds from the list of approved chemicals (Table 12). Although none of these chemicals appears in US traded pesticide formulations, they have been recorded in pesticide products in other countries such as Oman (Said Al Zadjali, personal communication).

Table 12 Pesticide inert ingredients with their approved status in doubt as the US EPA proposes their withdrawal

	CAS Reg. No	Chemical Name		CAS Reg. No	Chemical Name
1	109-89-7	Diethylamine	37	16919-19-0	Ammonium fluosilicate
2	78-93-3	Methyl ethyl ketone	38	1762-95-4	Ammonium thiocyanate
3	109-99-9	Tetrahydrofuran	39	25013-15-4	Vinyl toluene
4	123-92-2	1-Butanol, 3-methyl-, acetate	40	25154-52-3	Nonylphenol
5	80-62-6	Methyl methacrylate	41	2761-24-2	Amyl triethoxysilane
6	100-02-7	p-Nitrophenol	42	28300-74-5	Antimony potassium tartrate
7	10024–97-2	Nitrous oxide (N2O)	43	50-00-0	Formaldehyde
8	100-37-8	2-(Diethylamino)ethanol	44	533-74-4	Dazomet
9	101-68-8	4,4-Methylenedi(phenyl isocyanate)	45	552-30-7	Trimellitic acid andydride
10	106-88-7	1,2-Butylene oxide	46	618-45-1	o-m-p-Isopropylphenols
11	107-18-6	Allyl alcohol	47	71-55-6	1,1,1-Trichloroethane
12	107-19-7	Propargyl alcohol	48	7440-37-1	Argon
13	108-46-3	Resorcinol	49	74-84-0	Ethane
14	110-19-0	Isobutyl acetate	50	75-43-4	Dichloromonofluoromethane
15	110-80-5	Ethylene glycol monoethyl ether	51	75-45-6	Chlorodifluoromethane
16	112-55-0	Dodecyl mercaptan	52	75-68-3	1-Chloro-1,1-difluoroethane
17	117-81-7	1,2-Benzenedicarboxylic acid, bis(2-ethylhexyl) ester	53	75-69-4	Trichlorofluoromethane
18	117-84-0	Dioctyl phthalate	54	75-71-8	Dichlorodifluoromethane
19	119-61-9	Benzophenone	55	76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane
20	121-54-0	Benzenemethanaminium, N,N-dimethyl-N-(2-(2-(4-(1,1,3,3-tetramethylbutyl) phenoxy)ethoxy)ethyl)-, chloride	56	7758-01-2 x	Potassium bromate
21	123-38-6	Propionaldehyde	57	78-88-6	2,3-Dichloropropene
22	124-16-3	Butoxyethoxypropanol	58	79-11-8	Monochloroacetic acid
23	1303-86-2	Boron oxide (B2O3)	59	79-24-3	Nitroethane
24	1309-64-4	Antimony trioxide	60	79-34-5	1,1,2,2-Tetrachloroethane
25	131-11-3	Dimethyl phthalate	61	8006-64-2	Turpentine, oil
26	131-17-9	Diallyl phthalate	62	83-79-4	Rotenone
27	1317-95-9	Tripoli	63	85-44-9	Phthalic anhydride
28	1319-77-3	Cresol	64	88-12-0	N-Vinyl-2-pyrrolidone
29	1321-94-4	Methyl naphthalene	65	88-69-7	2-Isopropylphenol
30	1338-24-5	Naphthenic acid	66	88-89-1	2,4,6-Trinitrophenol
31	139-13-9	Aminotriethanoic acid	67	94-36-0	Benzoyl peroxide
32	141-32-2	Butyl acrylate	68	95-48-7	o-Cresol

(continued)

Table 12 (continued)

	CAS Reg. No	Chemical Name		CAS Reg. No	Chemical Name
33	142-71-2	Copper acetate	69	97-63-2	2-Propenoic acid, 2-methyl-, ethyl ester
34	149-30-4	2-Mercaptobenzothiazole	70	97-88-1	Butyl methacrylate
35	150-76-5	p-Methoxyphenol	71	98-54-4	p-tert-Butylphenol
36	150-78-7	1,4-Dimethoxybenzene	72	99-89-8	o-m-p-Isopropylphenols

Source: www.federalregister.gov/articles/2014/10/22/2014-24586

Table 13 Most frequently produced generic pesticide active ingredients as of 2006

Rank	Active ingredient	Activity	Number of manufacturers
1	Glyphosate	Herbicide	39
2	Chlorpyrifos	Insecticide	33
3	Cypermethrin	Insecticide	31
4	Carbendazim	Fungicide	23
5	2,4-D	Herbicide	23
6	Imidacloprid	Insecticide	22
7	Acephate	Insecticide	20
8	Mancozeb	Fungicide	20
9	Endosulfan	Insecticide	17
10	Fenvalerate	Insecticide	17

Source: PAN-UK [40]

Finally, it should be mentioned that increasing frequency with which so-called "Me-too" or generic pesticide formulations are entering the crop protection market. The increasing trend in market share occupied by off-patent pesticides has been recognised for some time [54] and is set to increase dramatically with an estimated $4 billion worth of pesticides set to come off-patent by 2020 (news.agropages.com accessed 28 November 2015). The most frequently produced generic pesticides (Table 13) are gaining an increasing market share not only in less developed countries [3] but also in Europe, North America and elsewhere [40]. Between them China and India have over 50% of the manufacturing companies producing generic pesticides [40].

With the increasing market penetration by generic pesticide products comes a concern for ensuring product quality. Research on generic abamectin-containing products from Turkey has shown significant differences in efficacy of active ingredients against specific insect targets, and variations in active ingredient content away from the label specification, by as much as 69% [17]. The risk here is that farmers, in response to reduced efficacy, are tempted to increase dose rates and/or frequency of application with a concomitant enhancement of risk through human and environmental exposure.

4 Worker, Environment and Consumer Exposure and Risk Assessment

Earlier the discussion touched on the inappropriateness of the EIQ and similar systems to provide a reliable indicator of the risk of pesticide use due to the method by which its mathematical equation was constructed using essentially qualitative labels. Exposure is the actual (rather than surrogate qualitative label) environmental or dietary concentration of a pesticide active ingredient [41]. Discussion of exposure must also, therefore, encompass the routes by which exposure loads are generated. Such a discussion thus includes farm practices in relation to pest and disease management: farmer decision-making, especially problem diagnosis and the appropriateness of the response.

Minimizing downstream pesticide exposure relies on maximizing the efficacy of decision-making at the farmer level. Briefly, the decision chain followed during effective pest and disease management begins with correct diagnosis and quantification of the problem, followed (in the current context) by the selection of an appropriate chemical. The chain then relies on accurate mixing of the correct dose and its application at the proper rate using appropriate technology and under conditions conducive to effective delivery to the plant. Finally, the process requires that the crop should not be harvested prior to the implementation of the pre-harvest interval (waiting period) for the specified crop/pesticide combination. At the same time the process of pesticide application to minimize exposure, should require use of personal protective equipment (PPE) and knowledge of appropriate disposal methods for empty containers and unused mixes.

Correct problem diagnosis is a serious problem in many developing countries where extension services may be non-existent, poor or inaccessible. Diagnosis might be based on the type of damage rather than the true causal agent [39] and application of control measures may be more related to the perceived value of the crop rather than the actual need for protection. The ability to make an accurate link between the problem and the most appropriate active ingredient is frequently lacking [44]. Application equipment selection is frequently limited by availability and in many developing countries the knapsack sprayer is routinely used and not infrequently misused [35] even though this may not be the most appropriate tool for some pesticides. Non-observance of the appropriate pre-harvest is commonplace [15, 58]. Consequently, where any one or more of these factors are present, worker and indeed downstream exposure to pesticide active ingredients is likely to be raised.

There is a further set of factors that mitigate against the minimizing exposure to pesticides. These factors involve the attitude towards safety of those responsible for pesticide applications, either through lack of knowledge or wilful neglect of regulations. Many reports exist of poor adherence to the required use of personal protective equipment (PPE) and lax protocols for the disposal of empty containers and unused pesticide mixes (see for example [2, 4]). As Al Zadjali et al. [4] report, a cavalier attitude towards personal safety is unlikely to accompany concern towards

Table 14 US EPA occupational pesticide handler unit exposure surrogate reference table

Exposure scenario (Activity, formulation etc)	Exposure route	Personal protective equipment level	Unit exposure (ug/lb ai)
Mixing/loading wettable powders	Dermal	No gloves	3700
		Gloves	170
		Double layer clothing, gloves	130
		Water soluble packaging	9.8
	Inhalation	No respirator	43.4
		PF5 respirator	8.68
		PF10 respirator	4.34
		Water soluble packaging	0.24
Applicator, open cab groundboom sprayer	Dermal	No gloves	9.9
		Gloves	7.2
		Double layer clothing, gloves	4.2
		Enclosed cab	2
	Inhalation	No respirator	1.2
		PF5 respirator	0.24
		PF10 respirator	0.12
		Enclosed cab	0.22
Applicator, granules by hand	Dermal	No gloves	104,000
		Gloves	71,000
		Double layer clothing, gloves	40,280
	Inhalation	No respirator	470
		PF5 respirator	94
		PF10 respirator	47
Mixer/loader/applicator, backpack crop sprayer, ground/soil directed	Dermal	No gloves	8260
		Gloves	8260
		Double layer clothing, gloves	4120
	Inhalation	No respirator	2.58
		PF5 respirator	0.516
		PF10 respirator	0.258

Extracted from: US EPA [57]

the potential for pesticide residues in food or environment. Models to assess the likely exposure of farm workers to pesticides such as the European EUROPOEM II suggest that, merely through the use of gloves as a single form of PPE, worker exposure is reduced by a factor of 5 [19].

Of course, access to advanced pesticide application machinery is limited in less developed countries. Consequently, the potential exposure to pesticides is likely to be far higher. Table 14 shows an extract of the data compiled by the US EPA (Pesticide Handlers Exposure Database, PHED) to model exposure factors for farm worker operations and the level (if any) of PPE used [57]. The values in Table 14 are surrogates to be used in model development, but are consistent with data obtained experimentally. The data shows that a farm worker in a less developed country who (a) does not use PPE, (b) mixes and loads the pesticide himself and (c) applies that pesticide using a knapsack sprayer (see for example [2]) has a potential exposure 100 times greater than an applicator using modern tractor driven machinery with an enclosed cab. The PHED database also includes other exposure scenarios and is an invaluable tool in estimating potential risks resulting from pesticide use, including risks to the health of farm workers (see for example [1, 13, 16, 33, 38, 42]). In Europe, the European Food Standards Authority (EFSA) is carrying out similar assessments of exposure under different scenarios that might affect farm workers, by-standers and residents [18].

Ecological exposure hazards arise due to escape, out of the farming environment, of pesticide ingredients. In the USA, the EPA is responsible for conducting ecological hazard assessments to determine what risks are posed by a pesticide and whether changes are necessary to protect the environment. The results of these assessments inform the pesticide registration process. Toxicity data submitted in support of registration is evaluated with respect to potential hazards posed to non-target fish and wildlife species. Assessments are made for direct and indirect (food chain) effects. The EPA and similar authorities elsewhere also assess the hazards posed through the interaction of pesticides with soils, air, sunlight, surface water and ground water. Potentially hazardous exposures are affected by the method and speed by which pesticides degrade and the toxicities of the breakdown products that result. Of critical importance also is the method and route by which pesticides or their breakdown products travel from the application site where they accumulate in the environment. Long term exposures are effected by the active ingredients break down in water, soil, and light; and how easily they evaporate in air; and how quickly they travel through soil. More recent studies have been accumulating on the ease with which pesticides are removed from foliage by direct contact or by weather events. For example, the EUROPOEM II model suggests that the so-called transfer coefficient (TC) of pesticides from the crop surface to harvesting workers can be substantial, presumably the TC to casual bystanders could also be significant. The rate at which pesticides degrade on the plant surface is measured as the foliar half-life (Table 15 for selected active ingredients). The foliar half-life will then have a bearing on the extent to which pesticide active ingredients or their breakdown products will enter the non-agricultural arena. For those seeking more information about the assessment of pesticide exposures in the soil and for terrestrial and aquatic ecosystems and the consequent potential risks might consult the US EPA resource at www.epa.gov/pesticide-science-and-assessing-pesticide-risks.

Pesticide exposure through the dietary route comes about as exposure through consumption of both food and water; active ingredients as residues on food items and active ingredients that have seeped into the groundwater and contaminated the drinking water supply. Maximum residue levels (MRL, or Tolerances in the USA) are established in many countries to set an upper limit to the potential exposure to pesticides in foodstuffs. In the USA, the EPA establishes tolerances for each crop use of a pesticide after developing a risk assessment (see below) that considers:

- The aggregate, non-occupational exposure from the pesticide;
- The cumulative effects from exposure to pesticides that have a common mechanism of toxicity;

Table 15 Foliar half-life (in days) for selected pesticide active ingredients

AI Name	Foliar half-life	AI Name	Foliar half-life
2,4,5-T, triethylamine salt	10	Fluazifop-p-butyl	4
2,4-DB, ester	9	Fosetyl-Al	0.1
Aldrin	2	Glyphosate (ANSI)	3
Arsenic acid	10,000	Imazapyr (ANSI)	30
Atrazine (ANSI)	5	Imazethapyr (ANSI)	30
Azoxystrobin (BSI, ISO)	3	Imidacloprid	3
Benomyl (ANSI)	6	Isofenphos	30
Bifenthrin (ANSI)	7	Lindane	3
Captan (ANSI)	9	Maneb	3
Carbaryl (ANSI)	7	Mecoprop	10
Carbofuran (ANSI)	2	Metalaxyl (ANSI)	30
Chlordane	3	Methidathion (ANSI)	3
Chloroneb (ANSI)	30	Methomyl (ANSI)	1
Clomazone (ANSI)	3	Oxadiazon (ANSI)	20
DDT	4	Parathion (ANSI)	4
Dicamba (ANSI)	9	Permethrin, mixed cis,trans (ANSI)	8
Dicloran	4	Prochloraz (ANSI)	30
Dieldrin	5	Profenofos (ANSI)	3
Dinoseb (ANSI)	10	Propargite (ANSI)	5
Endosulfan (ANSI)	3	Rimsulfuron (ANSI)	3
Endothall (ANSI)	7	Sethoxydim	3
Ethofumesate (ANSI)	10	Terbacil (ANSI)	30
Fenbuconazole (ANSI)	3	Thiabendazole	30
Fensulfothion	3	Thiophanate-methyl (ANSI)	5
Fenthion	2	Thiram	8
Ferbam	3	Triforine (ANSI)	5

Extracted from: EFSA [18]

- Whether there is increased susceptibility to infants and children or other sensitive subpopulations, from exposure to the pesticide and
- Whether the pesticide produces an effect in people similar to an effect produced by a naturally occurring oestrogen or produces other endocrine disruption-effects (www.epa.gov/pesticide-tolerances).

Some risk assessment methods work on the assumption that residues will be present in food at the maximum level permitted by the MRL or Tolerance. Other risk assessments use actual or anticipated residue data. In the USA, the Food and Drug Administration (FDA) enforce tolerances for non-meat foods (see Table 16).

Once pesticide residue data is available (either as MRL/Tolerances, or as actual residues) then this can be linked to consumption data that is frequently accessible through national surveys such as the US National Health and Nutrition Examination Survey/“What We Eat in America” (NHANES/WWEIA) dietary

Table 16 Selected US FDA pesticide residue tolerances for the fungicide azoxystrobin in selected food commodities

Commodity	Parts per million	Commodity	Parts per million
Almond, hulls	4	Pepper/eggplant subgroup 8-10B	3
Artichoke, globe	4	Peppermint, tops	30
Asparagus	0.04	Persimmon	2
Avocado	2	Pistachio	0.5
Barley, grain	3	Rapeseed subgroup 20A	1
Berry, low growing, subgroup 13-07G, except cranberry	10	Rice, grain	5
Brassica, head and stem, subgroup 5A[a]	3	Rice, wild, grain	5
Brassica, leafy greens, subgroup 5B	25	Rye, grain	0.2
Fruit, citrus, group 10–10	15	Star apple	2
Fruit, small vine climbing, except fuzzy kiwifruit, subgroup 13-07F	2	Starfruit	2
Fruit, stone, group 12[b]	1.5	Sugar apple	2
Herb Subgroup 19A, dried leaves	260	Sunflower subgroup 20B	0.5
Herb Subgroup 19A, fresh leaves	50	Tamarind	2
Lychee	2	Tomato subgroup 8-10A	0.2
Nut, tree, group 14	0.02	Vegetable, cucurbit, group 9	0.3
Onion, bulb, subgroup 3-07A	1	Vegetable, foliage of legume, group 7	30
Onion, green, subgroup 3-07B	7.5	Vegetable, leafy, except brassica, group 4	30
Papaya	2	Vegetable, leaves of root and tuber, group 2	50
Passionfruit	2	Vegetable, legume, edible podded, subgroup 6A, except soybean	3
Pawpaw	2	Vegetable, root, subgroup 1A[c]	0.5
Pea and bean, dried shelled, except soybean, subgroup 6C	0.5	Vegetable, tuberous and corm, subgroup 1C	8
Pea and bean, succulent shelled, subgroup 6B	0.5	Watercress	3
Peanut	0.2	Wax jambu	2
Peanut, refined oil	0.6	Wheat, grain	0.2

Extracted from: www.gpo.gov/fdsys/pkg/CFR-2014-title40-vol24/xml/CFR-2014-title40-vol24-part180.xml

[a]USDA reported residues for azoxystrobin in broccoli, peaches and carrot in 2013 were in the range 0.002–0.46 (75/708 positive broccoli samples, EPA tolerance 3.0 ppm), [b]0.002–0.13 (17/285 positive peach samples, EPA tolerance 1.5 ppm) and [c]0.01–0.031 (55/712 positive carrot samples, EPA tolerance 0.5 ppm) [55]

datasets (http://www.cdc.gov/nchs/nhanes/nhanes_questionnaires.htm) or the Dietary Exposure Evaluation Model - Food Commodity Intake Database (DEEM-FCID). Ongoing monitoring of chemical residues in food products of agricultural origin is performed by government bodies in various countries and the information gathered can be combined with pesticide toxicity datasets to construct probabilistic models that assess risk as a function of both exposure and toxicological information [53].

Systems such as the USDA Continuing Survey of Food Intake by Individuals (CSFII), the Dietary Exposure Evaluation Model–Food Commodity Intake Database (DEEM-FCID/CALENDEX) and Cumulative and Aggregate Risk Evaluation System (CARES) are being used to assess risk from dietary intakes of pesticides and microbes; they use the US EPA as a focus. Similarly, the EU has developed the Pesticide Residue Intake Model (PRIMo) for assessments of pesticide exposure through food intake (http://www.efsa.europa.eu/en/applications/pesticides/tools). The model is based on national food consumption figures and unit weights provided by EU Member States and implements internationally agreed risk assessment methodologies to assess the short-term (acute) and long-term (chronic) exposure of consumers. A third model system, LifeLine™ [52] is a tool for characterizing population-based aggregate and cumulative exposures and risks from pesticide residues in food and tap water as well as in the home following residential uses. LifeLine™ is a probabilistic model of exposures to pesticides applicable to the US and Canadian populations and select sub-populations. A summary of different model systems is shown in Table 17.

Finally, whilst there have been few studies that specifically address the cancer risk from chronic exposures to pesticide residues, Reiss et al. [45] compared the benefits of increased fruit and vegetable consumption with the risk associated with potential exposure to pesticide residues. Using standard risk assessment methods and EPA methodologies to estimate cancer risk for the dietary consumption of pesticide residues on food [56] the authors describe a general formula for estimating the lifetime risk associated with a given commodity–pesticide combination as follows:

$$LR = \overline{\mathrm{C}} \times \overline{\mathrm{R}} \times \mathrm{Q}_1^* / 1000$$

Table 17 A summary of three exposure-risk assessment model systems

Factor	LifeLine	DEEM/Calendex	CARES
Target of evaluation pathway	Food exposure, drinking water, residential exposure		
Food consumption material and population group character	CSFII survey/FCID, National Center for Health Statistics	CSFII survey/ FCID	CSFII survey and population census, CARES (stratified)
Residential pesticide monitoring material	Pesticide data program, total diet study etc		
Assessment result	Exposure rate (personal, aging, exposure pattern and exposure rate) and risk	Exposure rate and risk	Exposure rate and risk
Probabilistic approach	Distribution estimate	Distribution estimate	Distribution estimate

Source: Choi et al. [9]

DEEM dietary exposure evaluation model, *CARES* cumulative and aggregate risk evaluation system, *CSFII* continuing survey of food intake by individuals, *FCID* food commodity intake database

Table 18 Cancer unit risk values for pesticides

Pesticide	Q^*_1 (mg/kg/day)	Pesticide	Q^*_1 (mg/kg/day)
Carbaryl	0.000875	Fluometuron	0.018
Chlordane cis	0.35	Hexachlorobenzene (HCB)	1.6
Carbendazim	0.00239	Imazalil	0.061
DCPA	0.00149	Permethrin cis	0.0096
DDDo,p	0.24	Permethrin Total	0.0096
DDDp,p	0.24	Permethrin trans	0.0096
DDEp,p	0.34	Propargite	0.0033
DDTp,p	0.34	Tetraconazole	0.023
Dieldrin	16	Thiacloprid	0.0406
Diuron	0.0191	Trifluralin	0.0058
Fenbuconazole	0.00359		

Source: Reiss et al. [45]; this reference also provides citations for original source data

where: LR = lifetime cancer risk; $\bar{C}$ = average daily consumption of the commodity across the US population (g/kg bw/day); $\bar{R}$ = average residue level of a pesticide on the commodity (mg/kg of commodity consumed); Q_i^* = cancer unit risk factor $(mg/kg/day)^{-1}$ (Table 18). The factor of 1000 adjusts R to the grams of commodity consumed.

Reiss et al. [45] programmed dietary consumption data from CSFII and USDA pesticide residue data (see for example [55]) into the DEEM–FCID model to provide chronic dietary consumption data for all fruit and vegetable commodities by the general US population. The authors' resulting estimates are that approximately 20,000 cancer cases per year could be prevented by increasing fruit and vegetable consumption, while up to ten cancer cases per year could be caused by the added pesticide consumption. Of course, by the authors' own admission, the estimates have significant uncertainties (not least the reliance on rodent bioassays for cancer risk). Nonetheless "the overwhelming difference between benefit and risk estimates provides confidence that consumers should not be concerned about cancer risks from consuming conventionally-grown fruits and vegetables" [45].

5 Conclusions

The risks associated with pesticide use come about through the combined influences of active ingredient toxicities and the levels to which we are exposed to them in our diet, our employment or in our recreational activities. Over time we have seen a reduction in the toxicities of the pesticides available to farmers and food producers. National governments have become increasingly active in prohibiting the use of the most toxic active ingredients. International ingredients such as the Rotterdam and Stockholm Conventions have helped to raise the awareness of legislators to the dangers posed by certain active ingredients and families of actives. However, we have seen that within a commercial pesticide formulation, the active ingredient may constitute the minor part of the total content. To understand the potential for harm we need also to consider the role of the so-called inert ingredients. Inert ingredients may have the potential to be anything but inert; some may have toxicities as high as some active ingredients. Our future challenge is to understand the importance of these other ingredients in chemical exposures. We well understand the routes of exposures to pesticides. In the farming arena we can quantify the importance, in terms of reducing exposure, of accurate problem definition, appropriate pesticide selection and sensible application procedures. Our challenge here is to raise standards globally. For most of us, the risks from pesticides come from long-term exposures to small amounts of toxic chemicals. Recent developments in the modelling of the cumulative effects of these exposures helps us to guide legislators in their task of formulating future lists of allowed and prohibited active and inert ingredients. Finally, exposure data and risk models help us to understand the processes by which illnesses, including cancers develop. By understanding the process, we can aim to minimize the occurrence.

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Pesticide Food Laws and Regulations

Md. Nazibul Islam, Samavi Farnush Bint-E-Naser, and Mohidus Samad Khan

1 Introduction

In recent years, the use of pesticides has increased because of the increasing demand of agricultural crops and decreasing availability of agricultural lands [1, 2]. Pesticides are widely used in agriculture to reduce, and in some cases to eradicate insect-borne, endemic diseases by controlling insects, microorganisms, fungi, weeds, and other pests [3–5]. The control of these pests serves to enhance crop production, decrease manual labor, produce adequate food, and protect forests and plantations [2, 6–8]. However, indiscriminate use and improper handling of synthetic pesticides in agriculture may cause serious problems to human health, especially among farmers and farm workers [4, 9]. The impact and likelihood of the effects from acute pesticide poisoning (APP) can vary according to the chemical structure and characteristics of pesticides, pesticide dose quantity and frequency, route of exposure to pesticides and pesticide residues, and organ system, age, economic condition and education level of the victims [10]. Exposure to pesticides can occur via ingestion, inhalation, dermal absorption, or ocular contact.

Worldwide, there is a growing concern regarding the health effects caused by pesticide poisoning. Developing countries bear a disproportionate share of the poisonings and deaths caused by pesticides and pesticide residues, largely because of misuse of pesticides, poorer regulation, lack of surveillance systems, less enforcement, lack of training, and inadequate access to information systems. There are limited use of appropriate personal protective gears for the pesticide users and applicators [10, 11]. Developed countries also suffer from pesticide poisoning because of exposure to pesticides and pesticides residues. The heavy pesticide use

M.N. Islam • S.F. Bint-E-Naser • M.S. Khan (✉)
Department of Chemical Engineering, Bangladesh University of Engineering and Technology (BUET), Dhaka 1000, Bangladesh
e-mail: mohid@che.buet.ac.bd

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by the developed countries may contaminate water reservoirs and food chain with pesticide residues [12].

Rising sensitivity to the problems associated to pesticide use has given recognition to the need for increased worker protections from pesticide exposures, and reconsideration of pesticide use practices [9, 13]. The United Nations Food and Agricultural organization (FAO) developed the *International Code of Conduct* (1985) on distribution and application of pesticides with the purpose of bringing harmony among pesticide exporting and importing countries [2, 7]. To create legal binding obligations for the implementation of Prior Informed Consent (PIC) procedure, *The Rotterdam Convention* (1998) was adopted, which includes 72 signatories. There has been significant development in the regulation of pesticide sales, import, and use in both developing and developed countries after the convention.

At present, many countries have regulatory agencies and institutes responsible for the implementation of laws and regulations to control and monitor the use of pesticides. However, there is still lack of coordination among regional organizations. Countries from the same region have similar legislations with almost identical aims and objectives, therefore, synchronizing of all the existing laws into a single regional framework and compilation of a regional database can prove to be beneficial. This chapter aims to discuss, analyze, and compare the existing national, regional, and international laws and regulations related to the import, export, and use of pesticides around the world.

2 Global Perspective: International Conventions and Code of Conducts

In 1985, the Food and Agricultural organization of the United Nations (FAO) developed the *International Code of Conduct on Distribution and Use of Pesticides* in collaboration with World Health Organization (WHO), United Nations Environment Programme (UNEP), International Labor Organization (ILO), and other interested groups, such as International Group of National Associations of Manufacturers of Agrochemical Products (GIFAP) [2, 7]. The key purpose of this code was to bring harmony among industrialized pesticide exporting countries and pesticide importing countries. Prior to this code, there was a concern that different pesticides banned in their country of origin were exported to develop countries, which lacked the legal, technical, and administrative resources to access pesticide toxicity [2]. The code provides a Prior Informed Consent (PIC) portion, which aids the importing country with information concerning the pesticides being imported [7]. However, the code is voluntary and legally non-binding; the code was designed to act as an interim measure until local governments developed adequate regulations [2, 7].

To create legally binding obligations for the implementation of Prior Informed Consent (PIC) procedure, *The Rotterdam Convention* was adopted in 1998; the convention came into force in 2004 [14]. The *Rotterdam Convention* includes 72 signatories; 73% of the chemicals covered by the convention are pesticides. The objectives of *Rotterdam Convention* are to [14]:

- Promote shared responsibilities and cooperative efforts among parties in the international trade of certain hazardous chemicals in order to protect human health and the environment from potential harm;
- Contribute to the sound environmental use of certain hazardous chemicals by:
  - Facilitating information exchange about their characteristics,
  - Facilitating national decision-making process on their import and export, and
  - Disseminating these decisions to stakeholders.

According to the *Rotterdam Convention*, importing countries can take well informed decision by analyzing the "Import Responses Form" for a particular pesticide. They can also check the list of pesticides and industrial chemicals which were banned or severely restricted for health or environmental reasons by two or more parties. In addition, parties can report causes and impacts of pesticide poisoning through Severely Hazardous Pesticide Formulations (SHPF) Forms.

Relevant conventions of the *Rotterdam Convention* include *The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal*, and *The Stockholm Convention on Persistent Organic Pollutants*. *The Basel Convention,* which came into effect in 1992, aimed to reduce movement of hazardous waste between different nations. On the other hand, *The Stockholm Convention,* which came into effect on 2004, aimed to reduce the production and use of persistent organic pollutants (POPs) [15, 16].

One important initiative for pesticide management is the *FAO/WHO Joint Meeting on Pesticide Management (JMPM) and Annual Session of the FAO Panel of Experts on Pesticide Management*. The JMPM was established to ensure better cooperation between FAO and WHO for the sound management of pesticides. The annual meeting advises FAO and WHO on matters pertaining to pesticide regulation and management, and helps them implementing *International Code of Conduct on Pesticide Management* [17, 18]. Published in 2010, *The WHO recommended classification of pesticides by hazard and guidelines to classification: 2009*, classifies existing pesticides according to their toxicity, and also provides guidelines for future classification [19]. The *Codex Pesticides Residues in Food Online Database* is an important database, which contains the *Maximum Residue Limits (MRL)* and *Extraneous Maximum Residue Limits (EMRL)* for the pesticides adopted by the Codex Alimentarius Commission [20]. Based on the above discussion, it can be said that at present globally, there are different legal frameworks and scientific databases to address issues related to pesticide use, circulation, and possible health effects and environmental hazards. Successful implementation of the above codes and conventions based on the databases and MRL has the potential to curtail the harmful effects of pesticides.

3 Legal Status: Asia

3.1 ASEAN Countries

The Association of Southeast Asian Nations (ASEAN) is a political and economic organization of ten Southeast Asian countries. ASEAN member states are Brunei Darussalam, Cambodia, Indonesia, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Viet Nam. These countries regulate pesticide use through their national laws. In Cambodia, the *Law on the Management of Pesticides and Agricultural Fertilizer* is used to manage pesticide regulation [21]. The country is also a signatory of *Stockholm*, *Rotterdam and Basel Conventions,* and *Montreal Protocol* [22, 23]. The ministry of Agriculture, Forestry and Fishery (MAFF) is in charge of the overall management. In Indonesia, the following set of laws and decrees are followed for pesticide management [23]:

- *Government Law No. 12/1992*, on crop cultivation system.
- *Government Regulation No. 7/1973*, states that all pesticides which are distributed, stored, and commercialized inside Indonesia must be registered and need to take permit from the ministry of agriculture.
- *Minister of Agriculture Decree No. 24/2011*, on the guidelines and requirements for pesticide registration.
- *Minister of Agriculture Decree No. 42/2007*, on pesticide inspection.
- *Minister of Agriculture Decree No. 642/2012*, on the formation of Pesticide Committee. This committee is under the Ministry of Agriculture (MOA).

In Lao People's Democratic Republic, pesticides are controlled under the *Regulation on the control of pesticides in Lao PDR, No. 2860/MAF* [24]. The country has a list of 55 banned pesticides [22, 23], and is a signatory of *Stockholm*, *Rotterdam* and *Basel* Conventions. However, the latter two have not been fully implemented, yet [22]. The *Pesticides Act 1974 (amended 2004)* controls all activities related to pesticides in Malaysia [25]. This act is implemented by a 13 member Pesticides Board. The country is a signatory of all major conventions related to pesticide control, and has a list for banned pesticides and MRL for registered pesticides [23].

In Myanmar, *The Pesticides Law* establishes a Pesticide Registration Board (PRB) that takes care of the regulation of pesticides within the country. The law also elaborates the duties of pesticide sellers and license holders, the power of inspectors, and penalties for offences [26]. Other countries in the region also have their own authorities, such as the Fertilizer and Pesticide Authority (FPA) in Philippines, The Agri-Food and Veterinary Authority (AVA) and National Environment Agency (NEA) in Singapore, Pesticide Committees in Thailand, and Pesticide Board in Viet Nam that manage the use of pesticides in the respective countries [23]. These authorities are empowered with a number of laws, such as the *Hazardous Substance Act (No. 3) B.E. 2551* in Thailand, and *Circular No. 18, 2011* in Vietam, to effectively regulate pesticides [22, 23]. ASEAN countries have introduced hazard color bands to classify pesticides (Fig. 1) [22]. The ASEAN countries have the platform to combine their individual programs into a unified framework.

	Cambodia	Indonesia	LaoPDR	Malaysia	Myanmar	Philippines	Thailand	Vietnam	Harmonized Standard
Class Ia-1	Red	Brown	Red	Black	Red	Red	Red	Red	Red
Class Ib-2	Red	Red	Red	Red	Red	Red	Red	Red	Red
Class II-3	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Class III-4	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
Table 5-5 (Class IV)	*(No color)*	Green	Green	*(No color)*	Green	Green	Blue	Green	Green

Fig. 1 The summary of hazard color band for different hazard classes that are currently being used in ASEAN countries. Class Ia represents pesticides containing extremely hazardous active ingredients; class Ib represents pesticides containing highly hazardous active ingredients; class II represents pesticides containing moderately hazardous active ingredients; class III represents pesticides containing slightly hazardous active ingredients; and class IV represents pesticides containing active ingredients, which are unlikely to cause acute hazard in normal use [22]

3.2 SAARC Countries

The South Asian Association for Regional Co-operation (SAARC) includes Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka. These countries have national regulations to address pesticide management. In Bangladesh, the import, manufacture, formulation, repacking, sale, distribution, and use of pesticide are controlled by *The Pesticides Ordinance, 1971*. The ordinance provides the legal framework for setting up the *Pesticide Technical Advisory Committee* to advise the government on technical and legislative matters on relevant issues, which include false advertisement, false warranty, false registration number, and adulteration [27]. The Department of Agricultural Extension, Government of the People's Republic of Bangladesh provides the lists of registered and banned pesticides [28, 29].

In Bhutan, *The Pesticides Act of Bhutan, 2000* is used to ensure pesticide management. The act deals with imports, sales and use of pesticides, and enforces rules and procedures by laying the framework for appropriate authority and penalties [30]. In India, the pesticides regulations were governed by *The Insecticides Act 1968 and Rules 1971*, which has been replaced by *Pesticides Management Bill, 2008*. *The Pesticides Management Bill, 2008* that deals with different aspects of pesticide management, including production and distribution of pesticides [31, 32]. The registration of pesticides in India is performed by the Central Insecticides Boards and registration Committee (CIB & RC), which provides a list of registered and banned pesticides in the country [33].

In Nepal, the basic handling techniques of pesticide are covered by *The Pesticide Act, 1991*, and *The Pesticide Regulations, 1993*. Additionally, the maximum residue limit (MRL) for pesticide in some food product is described by *Food Act, 1994*, and *Food Regulations, 1970*. This MRL is monitored by the Department of Food

Technology and Quality Control (DFTQC) [34]. The *Agricultural Pesticides Ordinance, 1971* is the principle ordinance dealing with pesticide control in Pakistan [35]. Due to their shared origin and past history, this ordinance is identical to that used in Bangladesh. However amendments were made in 1992 and 2007 [36, 37]. The Government of Sri Lanka regulates its pesticide management with the help of *Control of Pesticides Act, No. 33 of 1980* [3]. The scope of the regulation is same as those in other SAARC countries. The above laws and regulations indicate that, most of the regulations of the SAARC countries have the same objective regulation of the import, manufacture, formulation, repacking, sales, distribution, and use of pesticides. Therefore, there is a scope for the SAARC countries to harmonize all the relevant laws into a single regional framework, and to compile a regional database.

3.3 Legal Status: Gulf Countries

The Cooperation Council for the Arab States of the Gulf originally known as Gulf Cooperation Council is a political and economic union of similar minded states of the Persian Gulf, namely, Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates. The aim of GCC is to promote coordination between member states in order to achieve unity. One of the many primary objectives of this council is to foster scientific and technical progress in agricultural and food industries [38]. The GCC countries have a common standardization organization, known as the Standardization Organization for G.C.C (GSO), which has a list of MRL for pesticides in agricultural and food products [39].

3.4 Legal Status: Other Major Asian Countries

People's Republic of China (PRC) is a signatory of *Stockholm*, *Rotterdam*, and *Basel Conventions* [23]. The following laws and regulations under different ministries regulate pesticides in China (PRC) [40]:

- *Provisions on Rural Pesticide Poisoning Sanitation Management*, under ministry of health to prevent rural pesticide poisoning and treatment.
- *Antitoxic Regulations for Storage, Transportation, Marketing and Use of Pesticides*, under General Administration of Quality Supervision, Inspection and Quarantine of the PRC to manage pesticide circulation and storage.
- *Agriculture Law of PRC*, regulates pesticide use in agricultural production, resources, and environment protection.
- *Provisions on Pesticide Advertisement Censorship*, issued by the State Administration for Industry & Commerce, Ministry of Agriculture, regulates advertisements related to pesticide.
- *Regulation on Pesticide Management*, issued by the state council, is the first comprehensive law to manage pesticides.

- *Provisions for the Implementation of the Regulation on Pesticide Management*, issued by the ministry of agriculture for proper implementation of the "Regulation on Pesticide Management".
- *Other regulations include Provisions on Pesticide Production Management*, *Guideline on Labels for Pesticide Products*, and *General Rule for Packing of Pesticides*.

The Democratic People's Republic of Korea (North Korea) has the *Law on Pesticides in Korea, DPR* to manage pesticides. Additionally, the country has *The Regulation on Handling of Substances with Toxicity in Korea, DPR* to control the circulation of toxic chemicals and pesticides [35]. Asia is a large continent with different administrative and economic systems. It is difficult to plan for a single framework for Asia to develop an integrated pesticide action plan; however, coordination among the regional organizations should be encouraged.

4 Legal Status: America

4.1 North America

In the United States of America, the Environmental Protection Agency's (EPA) Office of Pesticide Programs, regulates the manufacture, registration, and distribution of pesticides under the authority of the *Federal Insecticide, Fungicide and Rodenticide Act (FIFRA)* [8, 41]. The EPA enforces pesticide registration and regulation; it also provides support to the state and regional programs to protect, certify, and train pesticide applicants [41]. Other laws regulating the use of pesticides in USA are [42]:

- *Pesticide Registration Improvement Act (PRIA)*, which establishes the registration service fees for pesticide registration.
- *Federal Food, Drug, and Cosmetic Act (FFDCA)*, which authorizes EPA to set MRLs for pesticides used in or on food or animal feed.
- *Food Quality Protection Act of 1996 (FQPA)* amended *FIFRA* and *FFDCA* and set more strict safety standards for new and old pesticides.
- *Endangered Species Act (ESA)*, which ensures that the use of pesticides registered by EPA will not harm endangered species.

In Canada, The Pest Management Regulatory Agency (PMRA) of Health Canada has the mandate to protect Canadians from pesticide risk and provide them with safe pest management tool. In addition, the import, sell, and use of pesticide are regulated nationally by Pest Control Products Act and regulations (PCPA). The provinces and territories have some autonomy regarding pesticide management. A province/territory may prohibit or limit the use of a centrally registered product; however, it cannot authorize the use of a product that has not been registered under PCPA. For example, Quebec's "Pesticide Code" prohibits the use of more than 100 pesticides registered for the use in the rest of Canada [43, 44].

4.2 South America

In Argentina, *National Administration for Drugs, Food and Medical Technology (ANMAT) Provision 7292/98*, provides complementary standards for the registration process for chemical products [45]. In Brazil, the Brazilian Institute of Environmental and Renewable Resources (IBAMA) is the federal environmental agency responsible for pesticide regulation, and *Brazil Law Number 7.802* provides the legal framework for pesticide regulation [8]. *Decree 4.074/02* of *Law 7.802/89* provides all the instructions related to research, experimentation, transportation, storage, marketing, control, inspection, and other instructions related to pesticides. These regulations are implemented by three federal agencies: Ministry of Agriculture, Ministry of Environment, and the Ministry of Health [46]. In Chile, *Decree-Law No. 1 of November 8, 1989* sets activities required to express sanitary authorization for the manufacture and importation of pesticides. In addition, *Decree No. 157*, which is *Regulation on Pesticide for Sanitary and Domestic Use* provides regulations related to pesticide management [45].

5 Legal Status: Europe

In the European Union, *Regulation (EC) No 1107/2009* controls the marketing of plant protection products including pesticides [47]. The aim of this regulation is to synchronize the authorization of plant protection products within the EU. In addition, EC *Regulation 396/2005* provides a harmonized system of setting Maximum Residue Levels (MRLs) for all foods treated with pesticides. The EU Directive on the Sustainable Use of Pesticides provides a framework for sustainable use of pesticides [48]. In EU, no plant protection products can be used unless it is found that: (a) they have no harmful effects on consumers, farmers, or bystanders, (b) they do not provoke unacceptable effects on the environment, and (c) they are sufficiently effective. In December 2009, the European Union published four legislations, which make up the EU's *Thematic Strategy on Pesticides*. The legislations are [49, 50]:

1. *Plant Protection Products Regulation 1107/2009*: a regulation concerning the placing of plant protection products on the market.
2. *Sustainable Use Directive (SUD) 2009/128/EC*: a directive on the sustainable use of pesticides.
3. *Machinery Directive 2009/127/EC*:sets out standards for new equipment
4. *Statistics Regulation 1185/2009*: the key elements of this regulation are the provision of annual sales data, and the provision of data every 5 years on usage of crops and the pesticides used.

The aim of this strategy is to reduce risks on the environment and public health due to pesticide use, and to attain improved, sustainable use of pesticides [51]. In Russia, *Federal Law No 109 FL* regulates pesticide applications. Other rules to regulate pesticide applications in Russia include, *Russian Federation Government Resolution No 327*, *Order no 225,* and *Order of Ministry of Agriculture of Russian Federation no. 357*. These regulations manage the inspection and registration of pesticides within the federation. During registration, the trials are performed by the Ministry of Agriculture, and the assessment on biological effectiveness is carried out by All-Russian Institute of Plant Protection (VIZR), as well as other institutes [52].

6 Legal Status: African Countries

In Nigeria, the National Agency for Food and Drug Administration and Control (NAFDAC) is responsible for the regulation of pesticide management. To fulfill its mandate, the NAFDAC has several legislations at its disposal, which include *the Pesticides Registration Regulations*, and *the Chemical and Chemical Products Regulations*. There are various units under different directorates of the NAFDAC to regulate pesticides and other hazardous chemicals. For example, the Veterinary Drugs and Pesticides (VDP) unit under Registration and Regulatory Affairs directorate is responsible for pesticide registration; control of agrochemicals and pesticides are monitored by the Chemical Import Control (CIC) and Chemical Monitoring (CM) units under the Narcotics and Controlled Substance (NCS) directorate. Nigeria does not set MRLs, but adopts the Codex limit or that of the importing country [53–55].

In Egypt, the Agricultural Pesticide Committee (APC) is the legal authority for agricultural pesticide management and regulation. APC performs the legislative, monitoring, and judicial activities related to pesticides. The *ministerial Decrees 2188/2011* and *1018/2013* provide the legal framework for the formation and regulation of APC, respectively. In addition to APC, Egypt is also a signatory of the *1961 Codex Alimentarius*, *1989 Montreal Protocol*, *1991 International Plant Protection Convention*, and the *Basel*, *Stockholm*, and *Rotterdam Conventions* [56].

In Kenya, the Pest Control Products Board (PCPB) established under *the Pest Control Products Act in 1984* regulates the export-import, manufacture, distribution, and use of pesticides. PCPB also provides the lists of registered, restricted, and banned pest control products in Kenya [57]. In Tanzania, *the Tropical Pesticides Research Institute (TPRI) Act* ensures the effectiveness of pesticide use and protection of public health and safety. According to the *TPRI Act*, the importer has to follow procedures set by the *Pesticide Control Regulations, 1984* in order to import pesticides. Other rules and regulations to regulate pesticides in Tanzania include *Plant Protection Act, No. 13*, *Industrial and Consumer Chemicals (Management and Control) Act No. 3*, *Food, Drugs and Cosmetics Act No. 1*, *National Environmental Management Act, No. 20*, and *Occupational Health and Safety Act No. 5*. These regulations provide the required frameworks for pesticide use in different sectors of the country [58].

In Sudan, pesticide management is carried out under the *Pesticide and Pest control Products Act* [59]. The act regulates all activities related to pesticides in Sudan through the National Pesticides Council (NPC), which is a multidisciplinary council made up of representatives from Ministries of Agriculture, Health, Animal resources, Research Institutions, Customs, and Universities [60].

In South Africa, the *Fertilisers, Farm Feeds, Agricultural Remedies and Stock Remedies Act*, which is administered under the Department of Agriculture, Forestry and Fisheries (DAFF) governs pesticide management [61]. In Uganda, the Uganda National Agricultural Chemicals Board and the Agricultural Chemicals Control Technical Committee inspect and certify agrochemical trade in the country [62].

African countries at present have no integrated pesticide management program. However, continental integration is possible as most of the countries tend to have similar legislations. The African Union (AU) can play a vital role in establishing a continental action plan to manage pesticides. The regional platform of the European Union (EU) can serve as a good example to follow [49, 50].

7 Legal Status: Australia and New Zealand

Prior to 1995, the Commonwealth was responsible for the evaluation, assessment, and clearance of selected agricultural and veterinarian (AGVET) chemical products through the Australian Agricultural and Veterinary Chemicals Council (AAVCC). In 1995, the *Agricultural and Veterinary Chemicals (Administration) Act 1992* established the National Registration Scheme (NRS) under Commonwealth, and state and territory legislation, which is to be administered through the Australian Pesticides and Veterinarian Medicines Authority (APVMA) [63–65]. The Department of Agriculture and Water Resources manages the legislation under which the NRS operates [64]. The NRS legislation includes six other *Acts;* the key objectives of the *Acts* are [64, 65]:

- to deal with registration activities of pesticides,
- to regulate registration fees and charges, and
- to ensure that the AGVET chemicals are:
  - effective on target species,
  - safe, when exposed to humans and non-target species either through direct exposure or residues in treated food,
  - not a risk to the environment, and
  - labeled and packaged correctly.

The *Agricultural and Veterinary Chemicals Code Act 1994* empowers AVPMA, and addresses the operational provisions for the registration of products. The APVMA is responsible for the evaluation, registration, and regulation of AGVET chemicals. The use of pesticides is controlled and regulated by states and territories, individually.

In New South Wales, the Environmental Protection Agency (EPA) regulates the proper use of pesticides through the provisions of the *Pesticides Act 1999*. The EPA also provides guidance, through education programs and audits, and facilitates communication among different stakeholder groups to improve pesticide management [63]. In Victoria, the major administering agency to regulate agricultural chemicals is the Department of Natural Resources and Environment (DNRE). DNRE prohibits the off-label use of high-risk agricultural chemicals, and restricts application methods and frequencies of selected chemicals [63]. In Queensland, the pesticide use is governed by the *Agricultural Chemicals Distribution Control Act 1996 (ACDC Act)* and the *Chemical Usage (Agricultural and Veterinary) Control Act 1988 (Chem Use Act)* [63]. The major legislation relating to pesticide use in South Australia is the *Agricultural Chemicals Act 1955*, which regulates the sale and use of agricultural chemicals. The regulation is currently administered by the Farm Chemicals program, Primary Industries and Resources, South Australia (PIRSA) [63].

In Western Australia, the principal legislation relevant to the use of pesticides is the *Health (Pesticides) Regulations 1956,* which carries offences for using an unregistered pesticide, the use of registered pesticides at excessive rates and frequency of use, and the licensing of fumigators and pest control operators [66]. The regulation is currently administered by the Department of Health. Regulatory controls for the use of pesticides in Tasmania are imposed through the application of the *Agricultural and Veterinary Chemicals (control of use) Act 1995* [63].

The current legislation governing the control of use of pesticides in the Northern Territory is the *Poisons and Dangerous Drugs Act (1983),* which is administered by the Territory Health Services [63].

In New Zealand, the use of pesticide is governed by the *Pesticides Act 1979 (1979 No 26)*, *Pesticides Amendment Act 1987 (1987 No 16)*, and *Pesticides Amendment Act (No 2) 1987 (1987 No 44)* [67]. Under the *Hazardous Substances and New Organisms Act 1996*, agrochemicals such as pesticides (including insecticides, herbicides, and fungicides) that can be imported or manufactured in New Zealand require an approval from the New Zealand Environmental Protection Agency [67]. In addition, The Ministry of Primary Industries, Government of New Zealand, provides a database of the Pesticide MRLs for plant products [68].

8 Recommendations

The existing pesticide regulatory programs of different nations are similar in many procedural and utilitarian aspects. However, the fact remains that pesticide poisonings occur at a much higher rate in the developing and poorer countries [8]. One of the major factors contributing to this disparity is the inadequate transfer of related information from the regulators of the pesticide exporting countries to the regulators of the pesticide importing countries. Countries with the technological advancement and resources may take the lead to develop and register pesticides, and to disseminate information to the less advanced stakeholders. This transfer of information would enable the regulators of the developing countries to make informed decisions regarding pesticide risks. In addition, pesticide applicators and workers in the importing countries need adequate training and education regarding pesticide handling, applying, and storing [8].

A common regulatory system would be highly effective to regulate pesticide, globally; however, an international regulatory system binding all nations may not be feasible at this point. Regional entities are better positioned to offer a successful model to develop single regional framework to promote safe and beneficial use of pesticides. Harmonization of regional pesticide registration and regulation activities will boost sharing of resources, improving trade of agricultural products, and providing better protection of population and environment against pesticide hazards [11, 69].

9 Conclusion

Pesticides and pesticide residues are an important source of injury and illness among farmers and farm workers. Pesticide use is still substantial, widespread, and growing all over the world, and countries are looking for ways to permit people to experience the advantages of chemical pesticides without being endangered to their use. Different countries frequently import required chemicals to boost both home food production and export crop yields. Because of the lack of necessary bureaucratic infrastructure and forces, 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. Effective transfer of information is key to reducing many of the pesticide-related problems. This can be accomplished through cooperation and coordination among the pesticide exporting and importing countries. There are international codes of conducts and conventions to promote shared responsibilities and cooperative efforts among parties. Different countries also have specific laws and regulations to regulate pesticide. Combination of existing laws into a single regional framework, and compilation of a regional database can prove to be beneficial for countries from the same region.

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Management of Pesticides: Purposes, Uses, and Concerns

Afroza Begum, S.N. Alam, and M. Jalal Uddin

1 Introduction

It is reported that the world population is increasing by an estimate of 97 million per year, and by 2050, the world population would be ten billion [134]. To support the demand of growing population, the prime-most objective of many countries is to increase the food production. The Food and Agricultural Organization (FAO) of the United Nations has in-fact issued a sober forecast that world food production needs to increase by 70%, in order to keep pace with the demand of growing population. However, food production is now facing ever-growing challenges, especially the limited cultivation areas [134]. The increasing world population has therefore put a tremendous pressure on the existing agricultural system with limited resources like land, and water. In the process of increasing crop production, herbicides, insecticides, fungicides, nematicides, fertilizers and soil amendments are now being used at higher levels than the past. These chemicals have mainly come into the picture since the introduction of synthetic insecticides in 1940, when organochlorine (OCl) insecticides were first used for pest management. Beforce that most of the pests like weeds, insects and diseases could be controlled using sustainable practices, such as: cultural, mechanical, and physical control strategies [53]. Pesticide should not be used as unique and focal attempt, rather least harmful environmental friendly techniques should be applied first.

A. Begum • S.N. Alam (✉) • M. Jalal Uddin
Bangladesh Agricultural Research Institute, Gazipur 1701, Bangladesh
e-mail: alamsn09@gmail.com

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1.1 What Is Pesticide?

The Food and Agriculture Organization (FAO) has defined *pesticide* as: “any substance or mixture of substances intended for preventing, destroying, or controlling any pest, including vectors of human or animal disease, unwanted species of plants or animals, causing harm during or otherwise interfering with the production, processing, storage, transport, or marketing of food, agricultural commodities, wood and wood products or animal feedstuffs, or substances that may be administered to animals for the control of insects, arachnids, or other pests in or on their bodies. The term includes substances intended for use as a plant growth regulator, defoliant, desiccant, or agent for thinning fruit or preventing the premature fall of fruit. Also used as substances applied to crops either before or after harvest to protect the commodity from deterioration during storage and transport” [44].

The most common use of pesticides is to protect plant products. These chemicals in general protect plants from damaging influences of pests such as weeds, fungi, or insects. The use of pesticides is so common that the term *pesticide* is often treated as synonymous with *plant protection product* [125]. Pesticide may natural, organic, or synthetic, and can be used to control, prevent, kill, suppress, or repel pests. It is a broad term that includes insecticides (insect killers), herbicides (weed or plant killers), fungicides (fungus killers), rodenticides (rodent killers), growth regulators, and other materials like miticides (mite control), or products that kill snails and slugs (molluscicides).

1.2 Benefits of Pesticides

The following benefits can be attributed to pesticide use, such as:

1. To control pests and plant disease vectors, thus to improve yield and quality of crop.
2. To control human/livestock disease vectors and nuisance organisms, thus to save lives of human and animal as well as reduce suffering.
3. To control organisms that could harm other human activities and structures, thus to help preventing tree/brush/leaf hazards, and to help protecting wooden structures [27].
4. To save crops yields of four dollars ($4) against every dollar ($1) spent on pesticides [123].

In general, farmers are benefited by an increase in crop yield by being able to grow a variety of crops throughout the year. Consumers of agricultural products are also benefited from the vast quantities of produce available year-round [27]. The general public also benefits from the use of pesticides for the control of insect-borne diseases and illnesses, such as malaria [27]. In addition, the use of pesticides creates a large job market by engaging many peoples in the production and marketing of the pesticides throughout the world.

1.3 Use of Pesticide

Pesticides are used to protect agricultural land, stored grain, flower gardens as well as to eradicate the pests transmitting dangerous infectious diseases. It has been estimated that globally nearly $38 billion is spent on pesticides each year [116]. Manufacturers and researchers are designing new formulations of pesticides to meet the global demand. Ideally, applied pesticides should only be toxic to the target organisms, should be biodegradable and eco-friendly to some extent [131]. Unfortunately, this is rarely the case as most of the pesticides are non-specific and may kill the organisms that are harmless or useful to the ecosystem. In general, it has been estimated that only about 0.1% of the pesticides reach the target organisms and the remaining bulk contaminates the surrounding environment [18]. The repeated use of persistent and non-biodegradable pesticides has polluted various components of water, air and soil ecosystem. Pesticides have also entered into the food chain and have bio-accumulated in the higher tropic level. More recently, several acute and chronic illnesses to human have been associated with the exposure of pesticides [106].

2 Effects of Pesticides on Pest

There has been proliferation in the improvement of pesticides to target a broad spectrum of pests during the past years. The increased quantity and frequency of pesticide applications have posed a major challenge to the targeted pests, either disperse to new environment and/or adapt to the novel conditions [28, 103]. The adaptation of the pest to the new environment could be attributed to the several mechanisms, such as gene mutation, change in population growth rates, and increase in number of generations. This has ultimately resulted in the increased incidence of pest resurgence and appearance of pesticide resistant pest species [53]. Pest resistance, pest resurgence and secondary pest outbreaks are discussed in the following sections.

2.1 Pesticide Resistance

According to Insecticide Resistance Action Committee (IRAC), “Resistance may be defined as a heritable change in the sensitivity of a pest population that is reflected in the repeated failure of a product to achieve the expected level of control when used according to the label recommendation for that pest species” [75]. Resistant individuals insect population tend to be rare in a normal population, but indiscriminate use of chemicals can eliminate normal susceptible populations and thereby providing the resistant individuals a selective advantage in the presence of a pesticide. Resistant individuals continue to multiply in the absence of competition and eventually become the dominant portion of the population over generations. As majority of the individuals of a population become resistant, the insecticide is no longer effective, thus causing the appearance or development of insecticide resistance. Developing pesticide resistance is the most serious bottleneck in the successful use of pesticides these days. The intensive use of pesticides has led to the development of resistance in many targeted pest species around the globe [151]. Number of resistant insects and mite species had risen to 600 by the end of 1990, and increased to over 700 by the end of 2001. This trend is likely to be continued in twenty-first century as well. Resistance has been found in different insecticides groups e.g., 291 species have developed cyclodiene resistance, followed by DDT (263 species), organophosphates (260 species), carbamates (85 species), pyrethroids (48 species), fumigants (12 species), and other (40 species) [33]. Important crop pests, parasites of livestock, common urban pests and disease vectors in some cases have developed resistance to such an extent that their control has become exceedingly challenging [61, 158]. However, many factors such as genetics, biology/ecology and control operations influence the development of pesticide resistance [50]. Despite some associated drawbacks, insecticide bioassays using whole insects continued to be one of the most widely used approaches for detecting resistance [15, 60]. In the past two decades, however, several new methods employing advanced biochemical and molecular techniques, and combination of insecticide bioassays have been developed for detecting insecticide resistance [135, 150, 174]. Few examples of these techniques are enzyme electrophoresis, enzyme assays, immunoassays, allele-specific polymerase chain reaction (PCR) [53].

2.2 Pest Resurgence

Pest resurgence is defined as the rapid reappearance of a pest population in large numbers following pesticide application. Use of persistent and broad spectrum pesticides that kills the beneficial natural enemies is thought to be the leading cause of pest resurgence. However, resurgence is known to occur due to several reasons, for examples, increase in feeding and reproductive rates of insect pests, due to the application of sub-lethal doses of pesticides, and sometimes elimination of a primary pest provides favorable conditions for the secondary pests [33]. There are many pesticide-induced pest outbreaks reported in walnut (*Juglans regia*) [11], hemlock (*Conium maculatum*) [97], soybeans (*Glycine max*) [141], and cotton (*Gossypium hirsutum*) [13]. Among these, brown plant hopper (BPH) (*Nilaparvata lugens* (Stal)) in rice (*Oryza sativa* L.) cultivation has gained a major importance in Asian countries [23]. In general, natural BPH populations were kept under check by natural enemies including mirid bugs, ladybird beetles, spiders and various pathogens. However, the excessive use of pesticides have not only destroyed the natural enemies [40], but have influenced the fecundity of BPH females [161], thus further enhances their resurgence. Additionally, the resurgence of bed bug, *Cimex lectularius* [29] and cotton bollworm (*Helicoverpa armigera*) [105] have been reported due to insecticide resistance and indiscriminate use of pesticides.

2.3 Secondary Pest Outbreaks

Pesticides may kill not only the natural enemies of the concerned pest, but other pests as well. This resulted problems with pest species that were previously irrelevant. In some cases, natural enemies that normally keep minor pests under check, could be killed by the use of pesticides. This can result in secondary pest outbreaks [53]. The effect of pesticides on non-target organisms has been a source of worldwide attention and concern for decades. Adverse effects of applied pesticides on non-target arthropods have been widely reported [162]. Unfortunately, natural insect enemies, e.g., parasitoids and predators, are most susceptible to insecticides and these are severely affected by pesticide use [8, 160]. The destruction of natural enemies can exacerbate pest problems as they play an important role in regulating pest population levels. Usually, if natural enemies are absent, additional insecticide sprays are required to control the target pest. Supplementary insecticide sprays commonly cause secondary pest outbreaks.

3 Effects of Pesticides on Beneficial Organisms

Less than 2% of the insects in the world are harmful, most are beneficial insects. Consequences of toxic pesticides on natural enemy are unwanted and unsafe. The effect of pesticides on non-target organisms has been a source of worldwide attention. Unfortunately, natural insect, e.g., parasitoids and predators are most susceptible to insecticides [8, 160]. The devastation of beneficial organisms can make worse pest problems as they play a vital role in regulating pest population levels. Usually, if natural enemies are absent, additional insecticide sprays are required to control the target pest. In some cases, natural enemies that normally keep minor pests under check are also affected and this can result in secondary pest outbreaks. Along with natural enemies, population of soil arthropods is also drastically disturbed because of indiscriminate pesticide application [53]. Adverse effects on beneficial organisms, like predators, pollinators and earthworms are discussed in the following sections.

3.1 Predators

Predators are organisms that survive by preying on other organisms and they play a vital role in controlling pest populations. Predators are beneficial organisms, which play an important part of the "biological control". Selected examples are cited below when pesticides are the main cause for declining predator population:

- In brinjal (*Solanum melongena* L.) ecosystem, spraying with cypermethrin and imidacloprid caused higher mortality of coccinellids, braconid wasps and predatory spiders as compared to bio-pesticides and neem (*Azadirachta indica*) based insecticides [51].

- Species diversity, richness and evenness of collembola, and numbers of spiders were found to be lower in chlorpyrifos treated plots as compared to controlled grassland pastures in UK [46].
- Studies were carried out to investigate the effects of chemicals on soil arthropods in agricultural area near Everglades National Park, USA. It was found that higher number of arthropods (including predators such as coccinelids and spiders) were present in non-sprayed fields as compared to the fields sprayed with insecticides and herbicides [4].
- In foliar application, all the systemic neonicotinoids such as imidacloprid, clothianidin, admire, thiamethoxam and acetamiprid were found highly toxic to natural enemies in comparison with spirotetramat, buprofezin and fipronil [85]. Additionally, pesticides can also affect predator behavior and their life-history parameters including growth rate, development time and other reproductive functions. For example, in the eastern USA, glyphosate-based herbicides affected behavior and survival of spiders and ground beetles, apart from affecting arthropod community dynamics, this can also influence biological control in an agroecosystem [39]. Similarly, dimethoate was shown to significantly decrease the body size, haemocyte counts and reduction of morphometric parameters on carabid beetle (Pterostichus melas italicus), in Calabria, Italy [52].

3.2 Pollinators

Pollinators are biotic agents, play an essential part in pollination process. Some of the recognized pollinators are different species of bees, bumble bees (*Bombus* spp.), honey bees (*Apis* spp.), fruit flies, some species of beetles, and birds (e.g., hummingbirds, honeyeaters, and sunbirds) [53]. Pollinators can be used as bioindicators of ecosystemic processes (process by which physical, chemical, biological events help connecting organisms with their environment). In many ways, their activities are affected by environmental stress caused by parasites, competitors, diseases, predators, pesticides and habitat modifications [79]. However, pesticides causes direct loss of insect pollinators and indirect loss to crops because of the lack of adequate populations of pollinators [42]. Pesticide application also affects various activities of pollinators including foraging behaviour, colony mortality and pollen collecting efficiency. Most of our current knowledge about the effects of pesticides on the change in pollinator behaviour has come from various bee studies [53]. For instance, many laboratory studies demonstrated that the lethal and sub-lethal effects of neonicotinoid insecticides (imidacloprid, acetamiprid, clothianidin, thiamethoxam, thiacloprid, dinotefuran and nitenpyram) on foraging behavior, learning and memory abilities of bees [12]. Worker bee (female bees that lack full reproductive capacity and play many other roles in bee colony) mortality, decreased pollen collecting efficiency and eventually colony collapse occur due to pesticides (neonicotinoid and pyrethroid) application [59]. In addition to this, non-lethal exposure of honey bees to neonicotinoid insecticide (thiamethoxam) causes high mortality due to homing failure. This could be at a level that put a risk of colony collapse [70]. It has been anticipated that interactions between pathogens and imidacloprid pesticide could be the main reason of worldwide decrease of honey bee colony [122, 168]. There are reports, which indicates that imidacloprid reduced brood production due to decline in the fecundity of bumble bees (*B. terrestris*) [88, 164]. However, on the other hand, little work has been done to study the impact of pesticides on wild pollinators. For example, a field study carried out in Italy on an agricultural field found lower bumblebee and butterfly species richness associated with pesticide application. They also found that bees (insect pollinators) were at high risk from pesticide use [14].

3.3 Earthworms

Along with natural enemies, population of soil arthropods is also drastically disturbed because of indiscriminate pesticide application in agricultural systems. Soil invertebrates including nematodes, springtails, mites, micro-arthropods, earthworms, spiders, insects and other small organisms make up the soil food web and enable decomposition of organic compounds such as leaves, manure, plant residues etc. They are essential for the maintenance of soil structure, transformation and mineralization of organic matter [53]. Earthworms represent the greatest proportion of terrestrial invertebrates (>80%) [172]. Earthworms play a significant role in improving soil fertility by decomposing the organic matter into humus. Earthworms also play a major role in improving and maintaining soil structure; by creating channels in soil that enable the process of soil aeration and drainage. However, their diversity, density and biomass are strongly influenced by soil management. Because of these reasons, earthworms are considered as an important indicator of soil quality in agricultural ecosystems [117]. However, earthworms are affected by various agricultural practices, and indiscriminate use of pesticides is one of the leading causes affecting their populations [120]. Pesticide applications can cause decline in earthworm populations. For example, carbamate insecticides are very toxic to earthworms and some organophosphates have been shown to reduce earthworm populations [36]. Similarly, a field study conducted in South Africa also reported that earthworms were influenced detrimentally due to chronic and intermittent exposures to chlorpyrifos and azinphos methyl, respectively [127]. Various scientific studies reported that pesticides influence earthworm growth, reproduction (cocoon production, number of hatchlings per cocoon, and incubation period) in a dose-dependent manner [172]. Earthworms exposed to different kind of pesticides showed rupturing of cuticle, oozing out of coelomic fluid, swelling, and paling of body that led to softening of body tissues [145]. Similarly the combination of insecticides and fungicides at different concentrations caused neurotoxic effects in earthworms [136]. Increased exposure period and higher dose of insecticides can also cause physiological damage (cellular dysfunction and protein catabolism) to earthworms [136].

4 Effects of Pesticides on Human Health

Pesticides and pesticide residues can have lethal effect on human health. Toxic pesticides have the capacity to enter into the food chain and human body by direct contact with chemicals, through foods, and contaminated water and air. Both acute and chronic diseases can result from pesticide exposure.

4.1 Acute Disease

Acute illness generally appears a short time after contact or exposure to the pesticide. Pesticide drift from agricultural fields, exposure to pesticides during application and intentional or unintentional poisoning generally leads to the acute illness in humans [30, 91]. Several symptoms such as headaches, body aches, skin rashes, poor concentration, nausea, dizziness, impaired vision, cramps, panic attacks and in severe cases coma and death could occur due to pesticide poisoning [116]. The severity of these risks is normally associated with toxicity and quantity of the agents used, mode of action, mode of application, length and frequency of contact with pesticides and person that is exposed during application [129]. Every year, about three million cases are reported worldwide every year that occur due to acute pesticides poisoning. Out of these three million pesticide poisoning cases, two million are suicide attempts and the rest of these are occupational or accidental poisoning cases [143]. Suicide attempts due to acute pesticide poisoning are mainly the result of widespread availability of pesticides in rural areas [30, 129]. Several strategies have been proposed to reduce the incidences that occur due to acute pesticide poisoning such as restricting the availability of pesticides, substituting the pesticide with a less toxic but with an equally effective alternative and by promoting the use of personal protection equipment [84, 108].

4.2 Chronic Disease

Continued exposure to sub-lethal quantities of pesticides for a prolonged period of time (years to decades) results in chronic illness [116]. In the case of chronic pesticide poisoning, symptoms are not immediately apparent and manifest at a later stage. Agricultural workers are at a higher risk to get affected, however, general population is also get affected especially due to contaminated food and water or pesticides drift from the fields [116]. Incidences of chronic diseases have started to grow as pesticides have become an increasing part of our ecosystem. And there is mounting evidence that establish a link between pesticides exposure and the incidences of human chronic diseases. It can affect nervous, reproductive, renal, cardiovascular, and respiratory systems [106]. Chronic diseases like Cancer (Childhood and adult brain cancer; renal cell cancer; lymphocytic leukaemia (CLL); Prostate Cancer), neuro degenerative diseases including Parkinson disease, cardio-vascular disease including artery disease, diabetes (Type 2 Diabetes), reproductive disorders, hormonal imbalances including infertility and breast pain and respiratory diseases (Asthma, Chronic obstructive pulmonary disease (COPD)) are interrelated to the exposure of pesticides [2, 5, 10, 21, 25, 37, 65, 68, 69, 71, 90, 92, 102, 121, 142, 147, 152, 167, 169, 170].

5 Effects of Pesticides on Soil Environment

A major fraction of the pesticides used for agriculture and other purposes can be accumulated in the soil. The indiscriminate and repeated use of pesticides further aggravates this soil accumulation problem. Several factors, such as soil properties and soil microbes determine the fate of applied pesticides. The pesticide degradation process undergoes through a variety of degradation, transport, and adsorption/desorption processes [73, 86, 163]. The degraded pesticides interact with the soil and with its indigenous microorganisms, thus altering its microbial diversity, biochemical reactions and enzymatic activity [73, 107]. Pesticides that reach the soil can alter the soil microbial diversity and microbial biomass. Any alteration in the activities of soil microorganisms due to applied pesticides eventually leads to the disturbance in soil ecosystem and loss of soil fertility [67]. Numerous studies have been undertaken which highlight these adverse effects of pesticides on soil microorganisms and soil respiration [35, 144]. In addition to this, exogenous applications of pesticides could also influence the function of beneficial root-colonizing microbes such as bacteria and arbuscular mycorrhiza (AM), fungi and algae in soil by influencing their growth, colonization and metabolic activities [31, 101, 155].

Pesticides may also adversely affect the soils vital biochemical reactions including nitrogen fixation, nitrification, and ammonification by activating/deactivating specific soil microorganisms and/or enzymes [73, 107]. The synergistic and additive interactions between pesticides, micro-organisms and soil properties ultimately increase or decrease the rate of soil biochemical reactions. For example, populations of the *Azospirillum* spp. bacteria and the rate of ammonification was reported to increase at a particular pesticide concentration (i.e., 2.5–5.0 kg ha-1) in both laterite and vertisol soils used to plant groundnut (*Arachis hypogaea* L.). But the tested pesticides exerted antagonistic interactions on the population of *Azospirillum* spp. and ammonification at higher concentrations (7.5 and 10.0 kg ha-1) [148]. Pesticides have also been reported to influence mineralization of soil organic matter, which is a key soil property that determines the soil quality and productivity. For example, a significant reduction in soil organic matter was found after the application of four herbicides (atrazine, primeextra, paraquat, and glyphosate) [137].

5.1 Effects of Pesticides on Different Soil Enzyme

Pesticides in the soil may also disturb local metabolism or can alter the soil enzymatic activity [43, 62]. Soil in general contains an enzymatic pool which comprises free enzymes, immobilized extracellular enzymes and enzymes excreted by (or within) microorganisms. These are the indicator of biological equilibrium including soil fertility and quality [73, 96]. Degradation of both pesticides and natural substances in soil is catalyzed by this enzymatic pool [43, 83]. Due to this, measuring the change in enzymatic activity has now been classified as a biological indicator to identify the impact of chemical substances, which indicates pesticides in the soil biological functions [47, 130]. In fact, it has generally been assumed that measuring the change in enzyme activity is an earlier indicator of soil degradation as compared to the chemical or physical parameters [34]. Several studies have already been undertaken, which indicate both increase and decrease in activities of soil enzymes such as hydrolases, oxidoreductases, and dehydrogenase [76, 100].

Pesticides like, Carbendazim, Imazetapir, Thiram, Captan, 2, 4-D, Quinalphos, Monocrotophos, Endosulfan, γ-HCH, Butachlors reduce or inhibit the nitrogenase (i.e. an enzyme used by organisms to fix atmospheric nitrogen gas) activity in both laboratory and field conditions [22, 94, 110, 111, 124]. In addition, some pesticides also stimulate the nitrogenase activity [119]. Urease catalyzes the hydrolysis of urea into CO_2 and NH_3 and is a key component in the nitrogen cycle in soils. Pesticides (Isoproturon, Benomyl, Captan, Diazinon, Profenofos) increase urease activity [24, 113] and also reduced or inhibited urease activity [1, 74].

6 Pesticides in Water and Air Ecosystem

Pesticide residues in water are a major concern as they pose a serious threat to biological communities including human. There are different ways pesticides can reach into water, such as accidental spillage, industrial effluent, surface run off and transport from pesticide treated soils, washing of spraying equipment's after spray operation, drift into ponds, lakes, streams and river water, aerial spray to control water-inhibiting pests [19, 143]. Pesticides generally move from fields to various water reservoirs by runoff or in drainage induced by rain or irrigation [87]. Similarly, the presence of pesticides in air can be caused by a number of factors including spray drift, volatilization from the treated surfaces, and aerial application of pesticides. The extent of spray drift depends on: droplet size and wind speed. The rate of volatilization is dependent on time after pesticide treatment, the surface on which the pesticide settles, the ambient temperature, humidity and wind speed and the vapor pressure of the ingredients [82]. The volatile or semi-volatile nature of the pesticide compounds similarly constitutes an important risk of atmospheric pollution of large cities [156]. For instance, organophosphorus (OP) pesticides were identified from environmental samples of air and surface following agricultural spray applications in California and Washington (USA) [6]. In Italian forests, indiscriminate use of pesticides and its active metabolites has led to the contamination of water bodies and ambient air, possibly affecting the health of aquatic biota fishes, amphibians and birds [157].

7 Management and Strategies for Pesticide Use

There are few pesticide management strategies which could significantly reduce pesticide related risks. Few of those are: monitoring of pest population in field before any pesticide application, alteration of pesticides with different modes of action, restricting number of applications over time and space, avoiding unnecessary persistence, targeting pesticide applications against the most vulnerable stages of pest life cycle, and using synergists (i.e. enhance the toxicity of given pesticides by inhibiting the detoxification mechanisms). The most difficult challenge in managing resistance is not the unavailability of appropriate methods but ensuring their adoption by growers and pest control operators [33]. Pest resurgence is a dose-dependent process and there are ways to tackle this problem using correct dosage of effective and recommended pesticides. Resurgence problem occurs due to a number of reasons. One of them is the application of low-dose insecticides due to economic constraints that could lead to inadequate and ineffective control of pests. Pest resurgence also occurs due to reduced biological control (most common with insects), reduced competition (most common with weeds; monocots vs. dicots), direct stimulation of pest (due to sub-lethal dose), and improved crop growth. Optimized use of pesticides is important to reduce environmental contamination while increasing their effectiveness against target pest. Both pesticide resistance and pest resurgence problems might be reducing this way.

The use of natural control can be a safe option. If thre is a lack of healthy predator population in the agricultural ecosystem, then steps should be taken to increase their population. Natural predators such as lady beetles, mantises, spiders, and parasitic wasps can be purchased/reared and released in the field. Another option can be the use of pheromones that disturb the natural mating cycles of the pests. Sometimes trapping methods can also be employed. If further evaluation still shows the presence of pests, only then pesticides can be used. Target pesticides should be used before non-specific pesticides. Bio-pesticides are often more favorable than conventional pesticides. They are generally less toxic and are target specific than conventional pesticides. Bio-pesticides can often be applied in smaller doses and decompose faster than conventional pesticides. This can lower toxic exposure levels, environmental degradation and pollution. In the existing situation, optimized use of pesticides is important to reduce environmental adulteration while increasing their effectiveness against target pest. This has led to the consideration of rational use of pesticides, and the physiological and ecological selectivity of pesticides. Physiological selectivity is characterized by differential toxicity between taxa for a given insecticide. Ecological selectivity refers to the modification of operational procedure in order to reduce unnecessary destruction to non-target organisms [32]. Farmers should focus on using insecticides that are more toxic to target species than their natural enemies which could help to reduce resurgence to some extent [33]. Growers should consider adopting an Integrated Pest Management (IPM) approach for controlling pests, as these practices are designed to have minimal environment disturbance. The aim of IPM is not only to reduce indiscriminate pesticide use but also to substitute hazardous chemicals with safe chemistries. IPM is a process of achieving long-term, environmentally safe pest control using wide variety of technology and other potential pest management practices. According to National Academy of Science (USA), "IPM refers to an ecological approach in pest management in which all available necessary techniques are consolidated in a unified program so that populations can be managed in such a manner that economic damage is avoided and adverse side effects are minimized" [109]. In European arable systems, incentives to farmers to encourage the adoption of innovative IPM strategies is essential for the development of sustainable maize-based cropping systems. These IPM strategies can contribute immensely to address the European strategic commitment to the environmentally sustainable use of pesticides [159]. IPM strategy works for eco-friendly and long term pest control. Continuous use of pesticides leads to some inevitable problem like, pesticide resistance and pest resurgence. To avoid these issues, other potential management options could be used. These are cultural and physical control, host plant resistance, biological control, and the use of bio-pesticides, etc. These control strategies are discussed in the following sections.

7.1 Cultural Control

The goal of cultural control is to make the crop environment less suitable for insect pests. Most of the time, cultural control is used as a preventative measure. By anticipating insect problems before they occur, the control techniques could avoid or minimize the pest's impact on the crop. Cultural control techniques are the most effective when the target insect pests have few suitable host plants, do not disperse far or frequently, and/or have complex nutritional or environmental requirements during their life cycle. When using cultural control techniques, it is important to be aware of the environmental context of the field. Production efficiency, yields, soil conservation, natural enemy habitat should be taken into account for each crop/pest complex, climate, and surrounding environment. A cultural control technique aiming to maximize insect control for any specific context may not be pragmatic for a different context. For instance, the practice of tilling to disrupt an underground life stage of an insect pest may not be practical for a no-till farmer trying to reduce erosion on his or her field [133].

Cultural control for pest management has been adopted by growers throughout the world for a long time due to its environmentally friendly and minimal costs, and historically these methods were the most important tools for farmers to prevent crop losses [56]. Cultural control practices are regular farm operations, which are used to destroy the pests or to prevent them from plant damage. Several methods of cultural control have been practiced, such as crop rotation, sanitation, soil solarization, timed planting and harvest, use of resistant varieties, certified seeds, allelopathy, intercropping or "companion planting", use of farmyard manure, and living and organic mulches [3, 32, 33]. Soil solarization [58, 99] and organic mulches [176] alone and their integration [175] were reported as economical and eco-friendly technique for controlling soil-surface arthropods (various insects, and nematodes) [54, 55] and weeds [57, 58]. More effective cultural control can be achieved by synchronizing existing practices with life cycles of pests. This way the weakest link in their life cycle is subjected to adverse climatic conditions.

Large insect populations are killed automatically by farmers when they expose them to adverse climatic conditions through agricultural practices like weeding, ploughing, and hoeing. Ploughing of agricultural field allows turnover of the upper layer of soil while burying the weeds and residues from last year. For example, in South Africa, about 70% of overwintering populations of spotted stalk borer (*Chilo partellus*) and maize stalk borer (*Busseola fusca*) in grain sorghum (*Sorghum bicolor* L.) and maize (*Zea mays* L.) fields were destroyed by slashing the plants. Ploughing and discing of plant residues after slashing further destroyed 24% population on grain sorghum and 19% on maize [80]. Planting dates [64], and barrier crops (teosinte (*Zea* spp.) and pearl millet (*Pennisetum glaucum* (L.)) [63] were found to be effective against maize stem borer (*Chilo partellus*) in India. The brown seaweeds *Spatoglossum asperum* and *Sargassum swartzii* can be used as manure to protect plants (tomato (*Solanum lycopersicum* L.) in this case) from root rotting fungi, (*Macro- phomina phaseolina, Rhizoctonia solani and Fusarium solani*) and root-knot nematode (*Meloidogyne javanica*) and to provide necessary nutrients to plants [149]. In India, rodents are pests in agriculture, horticulture, forestry, animal husbandry as well as in human dwellings and rural and urban storage facilities. Cultural methods, such as clean cultivation, proper soil tillage and crop scheduling, barriers, repellents and proofing that reduce the rodent harborage, food sources and immigration may have long lasting effects [118].

7.2 Physical and Mechanical Control

Physical Pest Control is a method of controlling insects and small rodents by removing, attacking, or setting up barriers, that can prevent further destruction of one's plants. These methods are used primarily for crop growing [165]. These tools directly remove or kill pests, or physically keep insect pests from reaching their hosts by means of a barrier or trap. Some methods alter the physical environment to make it unfavorable to pests. Mechanical and physical controls have relatively little impact on natural enemies and other non-target organisms, and are compatible with biological controls. Physical control manages pest populations using devices, which affect them physically or alter their physical environment [53]. Exposure to sun rays, steaming, moisture management especially for stored grain, and light traps for attracting various kinds of moths, beetles and other pests are the methods used in physical control. For example, steaming woolen winter clothes help in eliminating population of the woolly bear moth, *Antherenus vorax* (waterhouse) [33]. Hot water treatment of plant storage products like corns, and bulbs, helps to kill many concealed pests such as eelworms and bulb flies. Superheating of empty grain storage godowns to a temperature of 50 °C for 10–12 h helps killing hibernating pests in stored grain. Exposure of cotton seeds to sun's heat in thin layers for 2–3 days during summer helps in killing diapausing larvae of pink bollworm (*Pectinophora gossypiella* Saunders) [33].

Mechanical control refers to suppression of pest population by manual devices. It includes various practices, such as hand picking, trapping and suction devices, clipping, pruning and crushing of infested shoots and floral parts, and exclusion by screens and barriers to keep away house flies (*Musca domestica*), mosquitoes and other pests. In south-eastern Australia, the common starling (*Sturnus vulgaris*) is an established invasive avian pest that is now making incursions into Western Australia and this makes no evidence of this species. Trapping with live-lure birds is suggested as the most cost-effective and widely implemented starling control technique [17]. Numerous wildlife species such as coyotes (*Canis latrans* Say), squirrels (Sciuridae family), and birds are known pests of California agriculture in the United States. For these pests, different non-lethal control options including habitat modification, exclusionary devices, and baiting are generally preferred [9]. Mechanical weed control is mainly associated with tillage practices and these are performed with special tools such as harrows, hoes, and brushes in growing crops. Increased knowledge about side effects of herbicides has further driven the interest in adoption of mechanical weed control thus increasing the prevalence of organic farming [77, 132]. Trapping using yellow colored sticky traps is an effective way for controlling tephritid flies [33].

7.3 Biological Control

The process of using natural enemies of particular pests to reduce their populations at a level where economic losses are either eliminated or suppressed and it is called biological control. Traditionally the most important biocontrol agents are parasitoids, predators and pathogens. Biological control involves three major techniques, *viz*., introduction, conservation, and augmentation of natural enemies. Biocontrol agents include vertebrates, nemathelminthes (flatworms, and roundworms), arthropods (spiders, mites, and insects), pathogens like viruses, bacteria, protozoa, fungi and rickettsiae and all play a dynamic role in natural regulation of insect and mite populations [33]. In 1762, the Indian Mynah, *Acridotheres tristis* (Linnaeus), was introduced to control red locust in Mauritius. First significant success in controlling a pest was achieved as suggested by C. V. Riley of California (USA) in 1888. The Vedalia beetle (*Rodolia cardinalis* (Mulsant)), was introduced from Australia into California (USA) for the control of cottony-cushion scale (*Icerya purchasi maskell*) on citrus plants. This scale insect had been accidentally introduced earlier from Australia [33]. Biological control of weeds has been very successful worldwide. There are about 41 species of weeds which have been successfully controlled using insects and pathogens as biocontrol agents. In addition, 3 weed species have been controlled using native fungi as mycoherbicides [98]. A total of 12 insects were released in Australia against prickly pear (*Opuntia stricta*), out of these, *Dactylopius opuntiae* and *Cactoblastis cactorum* were responsible for the successful control of prickly pear weed [78]. In the past decade, Australia has released 43 species of arthropods and pathogens in 19 different projects for successful biological control of many exotic weeds. Effective biological control was achieved in several projects and outstanding success was achieved in the control of rubber vine (*Cryptostegia grandiflora*), and bridal creeper (*Asparagus asparagoides*) [115]. Examples of biological control are available for other organisms like helminthes, nematodes, fungi, bacteria. A nematophagous fungus (*Monacrosporium thaumasium*) was found to be effective in controlling cyathostomin, one of the most important helminthes in tropical region of southeastern Brazil [153]. *Trichoderma* species are free-living fungi that have been used to control a broad range of plant pathogenic fungi, viruses, bacteria and nematodes especially root-knot nematodes (*Meloidogyne javanica* and *M. incognita*) [140].

Biorational pesticides Biorational pesticides/biopesticides are considered as third-generation pesticides that are rapidly gaining popularity. The word biorational is derived from two words, "biological" and "rational", which means pesticides of natural origin that have limited or no adverse effects on the environment or beneficial organisms. Biopesticides encompass a broad array of microbial pesticides, plant pesticides and biochemical pesticides which are derived from micro-organisms and other natural sources, and processes involving the genetic incorporation of DNA into agricultural commodities. The most commonly used biopesticides include biofungicides (e.g., *Trichoderma* spp.), bioherbicides (*Phytopthora* spp.), bioinsecticides (spore forming bacteria, *Bacillus thuringiensis*, and *B. popilliae*, Actinomycetes), naturally occurring fungi (*Beauveria bassiana*), microscopic roundworms (Entomopathogenic nematodes), Spinosad, insect hor- mones and insect growth regulators [66, 177]. Applications of microbial insecticide, Chromobacterium subtsugae used for suppression of pecan weevil (*Curculio caryae* (Horn), and combination of eucalyptus extract and microbial insecticide, Isaria fumosorosea (Wize) for control of black pecan aphid (*Melanocallis caryaefoliae* (Davis)). These were found promising as alternative insecticides [138]. Entomopathogenic nematodes (EPNs) belonging to the families Heterorhabditidae and Steinernematidae are potentially used in South Africa as biocontrol agents against vine mealybug (*Planococcus ficus* (Signoret)) [89]. Spinosad was found effective in controlling Colorado potato beetle (*Leptinotarsa decemlineata*) in Iran, and is recommended for use in IPM program for Colorado potato beetle [146]. In China, entomopathogenic fungus (*Beauveria bassiana*) has shown great potential for the management of some bark beetle species including red turpentine beetle (RTB) (*Dendroctonus valens* LeConte), a destructive invasive pest [173]. The allelopathic properties of plants can be exploited successfully as a tool for weed and pathogen reduction. In a rice field, application of allelopathic plant material at 1–2 tonne/ha reduced weed diversity by 70% and increased yield by 20%. Numerous growth inhibitors identified from these allelopathic plants are responsible for their allelopathic properties and may be useful source for the future development of bioherbicides and pesticides [171]. A combination of coleopteran-active toxin, Bacillus thuringiensis Cry3Aa protoxin and protease inhibitors, especially a potato carboxypeptidase inhibitor, have high efficiency in preventing damage to stored products and grains by stored grain coleopteran pests [114].

7.4 Host Plant Resistance

Host plant resistance (HPR) is the genetic ability of the plant to improve its survival and reproduction by a range of adaptations as compared to the other cultivars when exposed to the same level of pest infestation. HPR offers the most effective, economical and eco-friendly method of pest control [139], and is considered to be a key element of the IPM strategy. Due to this, identifying and developing HPR has always been a major thrust area of plant breeding, and worldwide a number of breeding programs are going on aiming to develop pest resistant crops. For example, identification and development of resistant varieties in maize against European corn borer (*Ostrinia nubilalis* (Hubner)) [33]. Brassica against cabbage butterfly (*Pieris brassicae* Linn.) [20], wheat (*Triticum aestivum* L.) and rye (*Secale cereale* L.) against Fusarium diseases [104], *Brassica* sp. against Sclerotinia disease [48], and in rice against bacterial blight [81] have been reported. Additionally, availability and access to various germplasm collections have increased the scope of widening the gene-pool of cultivated crops. Wild species are especially known to possess a rich repository of genes against various defense traits as they have evolved under different geographic locations. Considerable progress has been made in identifying and/or transfering resistance gene from wild to cultivated species. For example, potato (*Solanum tuberosum* L.) was developed against late blight (*Phytophthora infestans*) from ten wild *Solanum* sp. [26], wheat against powdery mildew (*Erysiphe graminis*) from wild emmer wheat (*Triticum dicoccoides*) [126] and mustard (*Brassica juncea*) against *Sclerotinia sclerotiorum* from *Erucastrum cardaminoides* [49].

7.5 Chemical Control

In many instances, cultural and other agro-technical practices are not sufficient to keep pest population below economic injury level (i.e. lowest pest population density that does not cause economic crop damage). Therefore, chemical control agents are resorted to both as preventive and curative measures to minimize the insect pest damage. A good pesticide should be potent against pests, should not endanger the health of humans and non-target organisms, and should ultimately break down into harmless compounds. Both relative and specific toxicities of the pesticide need to be estimated in order to determine its potency. It is very important to know spray droplet size and density of chemical dosage and application timing. There is also a need to develop suitable packaging and disposal procedures, as well as refining of the application equipment. All of these shall rationalize the use of pesticides, so that they can be used in an acceptable way. Very strict laws should be enacted to protect wildlife and other non-target organisms. Directions on the pesticide label should be followed to prevent injury to non-target organisms [42].

7.5.1 Selection of Appropriate Pesticide

The suitability of a pesticide depends on several elements, including accurate identification of damage and vulnerable stage of pest, mode of action of pesticides, compatibility, quality of pesticide and pre-harvest interval (PHI). All these elements should be considered carefully to achieve desired outcome, which are discussed in the following sections.

(a) **Nature of damage:** The first step of choosing a pesticide is the identification of the exact nature of damage of pest. Damage can also be the resulted from other factors, such as incorrect irrigation, poor drainage, herbicide toxicity, or physical damage. These, damage symptoms might also occurre by microorganism or insect. Nature of damage for pest differs from pest to pest. For example, some are sucking pest, some are cutting pest, some are chewing pest. Among these pests, certain pest attack at leaf or shoot, and other may cause injury to fruit. Some pest may cause harm to the outside of the host, other might be cause injury to inside of host plant. It is also important to identify the nature of the damage.

(b) **Identification of pest:** Correctly identification of the pest is necessary in selecting appropriate pesticide. Pest may be a specific insect, weed, or plant disease. An effective pesticide or other management strategy could be applied only when the pest is accurately identified. Identification of pest could be done with the help of research organization, extension office or other reliable sources. Proper identification of pests is must since all of the organisms present may not create the problem. Many of the organisms present may actually be beneficial in maintaining a balance in the insect community. An example of this is apparent in the aphid-praying mantis relationship. Aiming to rid farmers' field completely of aphids may cause further troubles by disrupting the food supply of the beneficial mantises. Accurate and continual monitoring will ensure that pesticide applications are necessary and correct pesticide is used, thus enabling grower to target certain pests without harm to others [38].

(c) **Vulnerable stage of pest:** Attacking stages may vary from pest to pest. Different stages of pest are harmful for different host. For instance, adult stage of mosquito is harmful for human and animals, while the larval stage of brinjal shoot and fruit borer attack or damage brinjal fruit and shoot. The application of pesticide is successful when applied at the most susceptible stage of the pest. Decision of insecticide application should coincide with the most vulnerable stage of insect life cycle. Monitoring of insects (i.e. biological stage) in the field is extremely important. Monitoring systems are available for most of the insect pests, but spray regime or experiments need to be carried out to determine the most appropriate time for insecticide application for insects for which monitoring systems are not available [72, 128]. The most susceptible stage of the pest for control measures will help to decide the time of application. At the time of pesticide choice, it is important to remember that most pesticides (even the more toxic ones) only affect at specific stages of the pest. Many insecticides kill pest only at the larval (e.g., caterpillars) stage, not the eggs or pupae. Other insecticides could be used to target only adults [166].

(d) **Specific Susceptibility to pesticides:** Different species of insects show wide range of susceptibility to insecticides. An insecticide can act only if it hits the vital parts of an insect. The habitat and the behavior of the species also play an important role. Different developmental stages of a pest species are also affected differently by a pesticide. In the pupal stage, an insect is often protected by a cocoon or by an earthen cell, and hence, it may survive pesticide effect. On the other hand, a larva is often vulnerable to insecticides [7]. Many fungicides are preventive treatments and these do not eliminate infections. Likewise, some herbicides (pre-emergence herbicides) kill germinating weeds but not established ones, while others (post-emergence herbicides) are effective against actively growing weeds [166].

(e) **Mode of action of pesticide:** Pesticides should choose according to their lethal action on the pests, such as stomach poisons, systemic poisons, contact poisons, and fumigants [7, 45].

Stomach poisons These types of pesticides are generally applied against insects having chewing mouthparts and under certain conditions also against insects with sponging, siphoning or lapping mouth parts. These poisons are also mixed with food for killing higher animals, such as rodents, jackals and birds. Pesticide like, lamda-cyhalothrin, alfa-cypermethrin, deltamethrin, chloropyrifos, fenvelerate are stomach poison.

Systemic poisons An insect with piercing mouthparts sucks cell-sap through its proboscis and embeds into the plant or animal tissue. Therefore, when a systemic insecticide when applied to seeds, roots, stems or leaves of plants, is absorbed and translocated to various parts of the plant. When insect sucks cell-sap, poison can reach the stomach of that insect through the toxic plant system. Thaiomethoxam, imidachlorpid, cartap, carbaryl, acephate pesticides showed systemic poison.

Contact poison These poisons kill the insects either by clogging spiracles and respiratory system or by entering through the cuticle into the blood and acting as nerve or general tissue poisons. These are applied in the form of dusts or as particles suspended in water, highly lipophilic and are readily absorbed by the lipid present in the epicuticle of the insect exoskeleton. Pyrethrum, neem extract, carbaryl and parathion are contact poison.

Fumigants These poisons kill insect pests in stored grains and other products in warehouses, museums. These insects found in animal sheds or in human dwellings, against soil-infesting grabs and nematodes, nursery stock, borers (i.e. trees or wooden structures), and greenhouse and intestines of animals. Since practically all the fumigants are deadly poisons, great care is needed in their use. Naphthalene, phosphine and methyl bromide are fumigants.

(f) **Compatibility:** Compatibility is another important factor during pesticide application. Since the farmers are interested in protecting the crop both from pests and diseases, insecticides and fungicides or even weedicides have to be mixed together before spraying. Some chemicals are compatible, whereas others are not; the former should not be mixed because they might become ineffective or the foliage might be damaged. Therefore the mixing should be done with the full knowledge or in consultation with an expert [7].
(g) **Quality of pesticide:** It is essential to choose an appropriate pesticide to produce quality product. An inappropriate pesticide will increase hazard in the crop field as well as in the environment. All pesticides contain active ingredients and inert ingredients. The active ingredients are the substances that perform the desired effect of the pesticide. Inert ingredients are mixed with the active ingredients to create the final product. These inert ingredients can have a several different purposes including the increase of the effectiveness of active ingredients, make the pesticide easier to use or apply, or allow several active ingredients to combine into a solution. The inert ingredients can make up as much as 99% of the final product [38]. If possible, Percentage of active ingredient (purity of pesticide) should checked before use of pesticide.
(h) **Persistency of pesticide:** Pesticides are used because they kill or control the target pest. "Selective" pesticides kill only a few closely related organisms. Others have a broader spectrum, killing a range of pests but also non-target organisms, cause negative impacts to the environment. For instance, some insecticides with low toxicity to human may possess high toxicity to beneficial insects, like parasitic wasps or other desirable organisms like honey bees, earthworms, or aquatic invertebrates. Most herbicides selectively kill some weeds, but can also kill desirable garden plants if not used properly. Persistency of pesticide or how long it remains toxic in the environment is also a factor. Pesticides that break down rapidly should have less negative impact on the environment, but these are more difficult to use. Because they do not leave toxic residues and kill pests arriving hours or days after the application, these pesticides must be applied precisely when the vulnerable stage of the pest is present [166].

The key words Danger, Warning, or Caution on a pesticide label indicate their immediate toxicity of a single exposure to humans. Over the years, these words have been the consumer's primary guide to relative safety of products. However, signal words do not give a proper indication of potential for causing chronic problems (e.g., cancer, reproductive problems or other long-term health effects). They also do not reflect potential hazards for wildlife, beneficial insects and many other non-target organisms [166].

The following words provide an indication of the relative acute toxicity of the product to humans and animals. The statement "keep out of reach of children" must also appear on the front panel of the label.

- Caution—these products are slightly toxic either orally, dermally, or through inhalation, or cause slight eye and skin irritation.
- Warning—these products are moderately toxic either orally, dermally, or through inhalation, or cause moderate eye and skin irritation.
- Danger—these products can cause severe eye damage or skin irritation.
- Danger—poison and the skull and crossbones symbol—these products are highly toxic by any route of entry [154].

(i) **Pre Harvest Intervals (PHI):** Along with the target pest and dose, label of pesticide carry pre-harvest interval of crop. To protect consumer from pesticide contaminated food, it is important to follow the time interval. The pre-harvest interval (PHI) refers directly to the number of days that must pass between the time of the last application of a pesticide and when the crop is harvested. The PHI does not include the time the crop is lying in the swath prior to combine. The residues in the products are only metabolized and broken down by living plants, but not by dead/cut plants in the field. PHI can vary depending on the crop being sprayed and the product being used. The same product may be registered for multiple crops but the PHI is different for each of those crops. The time of spraying in the growing season is also important. In canola, for example, pests that can be a problem later in the season, such as bertha armyworms and/or diamondback moths require spraying of pesticides closer to harvest. For late-season spraying, a product with a lower PHI, such as deltamethrin (Decis) or lambda-cyhalothrin (Matador, Silencer) need a PHI of 7 days, instead of products such as chloropyrifos (Losban, Pyrinex, Nufos, Citadel) need a PHI of 21 days, and cypermethrin (Ripcord) needs a PHI of 30 days. All commercial products have clearly defined PHIs on their labels and this information can also be found in The Guide to Crop Protection [16].

7.5.2 Application of Pesticide

Pesticides may not produce good results unless they are applied properly. Therefore, the quality of application of pesticides is very important in pest control operations. The proper application of pesticide cover proper dose of pesticide, proper droplet of pesticide and proper calibration of equipment. Proper selection of application equipment, knowledge of pest behavior and skillful dispersal methods are vital. During pesticide application, the location of the pest, timing of pesticide application, dose of pesticide, proper droplet of pesticide and calibration of equipment are the important factors.

(a) **Location of the pest:** The main purpose of pesticide application is to maximize the efficiency and minimize the efforts required to keep the pest under control as well as minimum contamination of non-targets. All pesticides are poisonous substances and they can cause harm to all living things. The application techniques ideally should be target oriented so that these are safe to the non-targets and the environment. Usually only about 0.1% of the applied pesticides are able to reach their target, while a large amount of it is wasted [18]. Understanding the pest biology and behavior is critical as it can provide information on pest's habitat, fecundity, feeding; and these can be important considerations before applying pesticides. A complete knowledge of pest problem is important to define the target i.e., location of the pest (on foliage, under the leaves, at root zone etc). Since the pest needs to be directly hit, the method or site of application of the poison would depend on its location. Insects feeding on the lower surface of the leaves have to be reached by the spray. Those feeding on the roots have to be killed by mixing insecticides with the soil, and those rising up the trunk of the trees have to be intercepted with sticky or poison bands [112].

(b) **Timing of pesticide application:** Appropriate application time can ensure maximum impact on the target organisms, and least impact on beneficial organisms. Pesticide application timing mainly depends on availability of weather window, time at which pests can be best controlled, and when least damage are caused to non-target organisms and environment. For example, flowering period in crops and middle of the day are the times when bees are more prone to insecticides. Hence, insecticide application should not take place at these times to avoid decline in bee populations [72, 128].

Time of the day and season of the year are also important to consider when applying pesticides. The early morning and evening hours are often the best times for pesticide application because windy conditions are more likely to occur around midday when the temperature warms near the ground level. This causes hot air to rise quickly and mix rapidly with the cooler air above it, favoring drift. During stable conditions, a layer of warm air can stay overhead and not promote mixing with colder air below and closer to the ground. Inversions tend to dissipate during the middle of the day when wind currents mix the air layers. It is very important that applicators recognize thermal inversions and do not spray under those conditions. A temperature or thermal inversion is a condition that occurs naturally and exists when the air at ground level is cooler than the temperature of the air above it. Wind speed is the most important weather factor influencing drift. High wind speeds will move droplets downwind and deposit them off the target. On the other hand, dead calm conditions are never recommended due to likelihood of temperature inversions [41]. Drifting of pesticides increases the possible injury to pollinators, humans, domestic animals and wildlife. It is recommended to avid spray in wind speed above 4.02 km/s, which can cause excessive drift and eventually contaminate adjacent areas [95]. Pesticide application should not be made just before rain because pesticides can be washed off by the rain without any impact on the target pest.

(c) **Dose of pesticide:** Pesticide dose should be sufficient and not greater than the level required for best results. The pesticide manufacturer sets the dose to ensure an acceptable level of control, acceptable residue levels, and maximize returns per unit of formulated insecticide. Persistent pesticides have their benefit of longer persistence on the target, and therefore require less frequent spraying as compared to non-persistent pesticides. But care should be taken while using persistent pesticides since these might diminish benefits from natural enemies even at lower doses [53]. If an insecticide is persistent in nature, chances of insecticide residues being harmful to natural enemies are greatly increased [32]. The recommended dosage are generally indicated for acre or hectare e.g. kg/ha or lit/ha or g ai/ha. It should be properly understood and the exact quantities of the formulated pesticide should be applied. The requirement and spray droplet size depends upon the mobility and size of the pest. In addition, the mode of action of pesticide, its relative toxicity and other physicochemical properties, help to decide how to handle with precautions, agitation requirement. The complete knowledge of the equipment is necessary to develop desired skill of operation, to select and to estimate the number and type of equipment are needed to treat the crop in minimum time and to optimize use of the equipment [112].

(d) **Proper droplet of pesticide:** Pesticides are dispersed by different methods like spraying, and dusting. Proper selection of equipment and skillful dispersal methods are important. Pesticides can be sprayed by different types of nozzles, such as hydraulic, air blast, centrifugal and heat energy. Water is a common carrier of pesticides but air or oils are also used as carriers. Selection of proper droplet is also an important consideration. The shape, size and surface of the target vary greatly. For example, spraying against flying insects by hydraulic nozzles will not be effective. Here fine size spray particles to remain airborne for longer time are needed. However, weed control operation usually the require drift free application or coarse spray droplets, and adequate number of spray droplets should be deposited [112]. For fungicide applications, the number of droplets deposited per unit area should be high. It may need fewer numbers of droplets to be deposited in case of highly mobile (crawling) insect pest. The pesticides are formulated in liquid form, dust powder or granule forms so that it can be applied small quantities of pesticides over large area. Some of the pesticides are applied as low as few gram active ingredient per hectare. The volume of spray liquid required for certain area depends upon the spray type and coverage, total target area, size of spray droplet and number of spray droplets. Most of the pesticides are applied in liquid form, thus the droplet size is very important in determining their effectiveness. It is obvious that if the spray droplets are coarse-size then the spray volume required will be larger than the small size spray droplets. Also if the thorough coverage (eg. both the sides of leaves) is necessary then the spray volume requirement needs to be more [112].

Small droplets provide better coverage and greater likelihood of coming in contact with the target as compared to larger droplets, which can be bounced off from the plant surface very easily. The disadvantage with smaller and bigger droplets is the increased chance of drift and therefore a balance has to be considered between smaller droplets for the maximum effectiveness and reduced drift. In situations where crops are grown on beds covered with plastic mulch, pesticides should be injected into soil at the time the plastic is laid or injected afterward through drip irrigation system to achieve maximum effectiveness. For termite (Order: Isoptera) treatments, sometimes perimeter application of insecticides is required around structures/buildings. Additionally, liquids that form foams during injections can be injected into small spaces so that these might be inhabited by termites or other small creatures [53].

(e) **Calibration of equipment:** The method of adjusting the pesticide application equipment for the even distribution of pesticide over the desired area is called Calibration [53]. This is the process of measuring and adjusting the amount of pesticide by equipment applies or delivers to a specific area. The purpose of calibration is to ensure the used equipment apply correct amount uniformly over a given area. Therefore adoption of proper application technique is vital for uniform depositing of pesticide. The measurement of properly concentrated formulations of pesticides is essential for their effective and safe use. The application rate for most insecticides and fungicides is given on the label in milliliter per liter of water. It is essential to dilute and apply materials as required according to these procedures. Before mixing up pesticide, sprayer should be tested out with water to assure the coverage of the recommended area with the suggested amount of diluted spray. If not, should be adjusted with application rate accordingly by walking or spraying slower or faster. Accurate calibration to determine the application rate under operating conditions is important for cost, efficiency, and safety. Calibration should be done every time for switching chemicals or changing application rates [112].

7.6 Safe Use of Pesticide

Most pesticides can cause serious damage to human health, if misused. However, every registered pesticide can be used safely. Many accidental pesticide deaths are caused by eating or drinking the product, particularly by young children. Some applicators die or get injured when they breathe pesticide vapor or get pesticide on their skin. Therefore, before using a pesticide, label of pesticide should be read carefully; according to the label, proper safety measure should be taken.

7.6.1 Prevention of Pesticide Exposure

It is important to protect the user from direct exposure to pesticides during application. The necessary protection equipment may vary depending on the protective needs prescribed on the pesticide labels. Wearing proper clothing and using safety equipment provides a layer of protection during handling, mixing, application, storage, and disposal of pesticide. The type of protective clothing and need of equipment depends on the job being done and the pesticide being used. The label of pesticide containing packet or bottle should be read carefully, and the user should follow all directions concerning necessary protective clothing and equipment, usually indicated on the label as personal protection equipment or PPE. Protective equipment should be kept clean and in good condition. Protective equipment includes the following:

Gloves Most exposure of pesticides occurs to the hands. This is especially true during pesticide mixing and loading. By wearing full-length plastic or rubber gloves, an applicator can almost eliminate pesticide exposure. The hands gloves should be in good condition (no holes or rips) and clean. Gloves should be made with proper chemical resistant material and it should be long enough to cover the wrist and lower fore arm.

Chemical Goggles It is important to use chemical goggles rather than general safety goggles. Chemical goggles include a baffled airway which inhibits splashes from entering the inside of the goggles [38].

Apron Pesticides can be quickly absorbed into the body through skin. Skin should be covered to reduce the risk of poisoning from dermal exposure. Protective clothing should include: a long-sleeved shirt, long-legged trousers or coveralls protective footwear Socks.

Waterproof Boots Applicators should wear unlined boots when mixing pesticides or walking through a treated area. These should be made of chemical-resistant materials (e.g., neoprene, nitrile, or polyvinyl chloride). The boots should reach above the ankle, and should be covered by the pant leg. This prevents liquid pesticides from running down into the boots and being absorbed through the skin. Rubber overshoes are suggested since they prevent absorption and these are easy to clean.

Mask/Respirator Mask or mask with respirator should be used to avoid inhaling of pesticide through mouth or nose.

Hat The absorption rate of pesticides is also very high on the scalp and forehead. Therefore, plastic caps are recommended as they are waterproof and prevent absorption.

Ear Protection Ear plugs prevent pesticide exposure via the ear canal [38].

The equipment should also be thoroughly cleaned with soap and water after every use to keep those ready for next use.

7.6.2 Pesticide Disposal

User should mix pesticide with water only as much as required, and should not store leftover pesticide solutions unless it is recommended. The pesticide mixture may be susceptible to quality changes at high or very low temperatures or by settling out. Empty containers of concentrated pesticides and left over pesticides should be disposed according to the instruction provided with pesticide packing.

7.6.3 Storage of Pesticide

Safe storage of pesticides requires attention to location and features of the storage facility (whether permanent or temporary). The pesticide storage should be located at a safe location, and should be made of fire-resistant materials. Entry to these storage facilities should be limited to authorized persons only. The pesticides should be kept in well ventilated store room. Pesticides should be stored in their original containers. Herbicides, fungicides and insecticides should be stored in separate locations of the storage area to prevent cross contamination and accidental misuse. Herbicides should be separated from other pesticides to prevent cross-contamination (especially wettable powders) since some herbicides are volatile [93].

8 Conclusion

Pesticide is important for the increase of food production, but the improper use of pesticide is detrimental to all creatures. Different adverse effects, such as, increasing number of resistant pest population, decline in the beneficial organisms such as predators, pollinators and earthworms, change in soil microbial diversity, and contamination of water and air ecosystem are increasing day by day. Moreover, some of the acute and chronic human illnesses have been developed as a consequence of contaminated food. Therefore, the adverse effects of pesticide use have overweighed the benefits. It is important to understand the term "unwise pesticide use". Alternative pest control strategies such as cultural control, use of resistant genotype, physical and mechanical control, and rational use of pesticide could reduce the amount of pesticide applications. Furthermore, progressive tactics such as biotechnology and nanotechnology could aid in developing resistant genotype or pesticide with fewer adverse effects. IPM strategies hold the key to reduce the deleterious impact of pesticides. In addition, suitable use of pesticides is necessary to protect environment, and eventually, health hazards associated with it. Before choosing pesticide, important aspects should be kept in consideration, such as proper identification of pest, mode of action of pesticide, quality and persistency of pesticide should be taken into consideration. Location of pest, timing of pesticide application, dose of pesticide, droplet size and quality, calibration of equipment should also be considered before pesticide application. Lastly, proper protection measures should be taken to avoid unnecessary pesticide exposure to the user as well as environment, and the pesticides should be stored in proper storage facilities.

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Pesticide Degradations, Residues and Environmental Concerns

Abdullah Al-Mamun

1 Introduction

Pesticide ingredients started to use versatilely after the second world war with the introduction of DDT (dichlorodiphenyltrichloroethane), BHC (benzene hexachloride), aldrin, dieldrin, endrin, and 2,4-D (2,4-dichlorophenoxyacetic acid) [1]. Now a day, approximately 1.0–2.5 × 10^6 tons per year of pesticides and their components are applied over the large fields of agricultural and urban premises to enhance the production of food and to limit the growth of pests [2, 3]. It is widely presumed that pesticides are toxic to targeted organisms and are harmless to non-targeted species. But this assumption does not hold true in most of the cases. Therefore, the applications of pesticide become a severe environmental concern. The ways of spreading contaminants by pesticides are not only from its application to food crops, but also from the unintentional release during transport and manufacturing, as well as from the accumulation of degraded by-products in crops and environment (i.e. soil, water, sediments) [4].

Although pesticides are useful in regulating pests, their unregulated and inappropriate applications cause adverse effects to human and ecosystem. These cause severe health hazards due to rapid fat solubility and bioaccumulation in non-targeted organisms [5]. Their adverse impacts depend on the degree of sensitivity of organisms to a specific chemical. The recurrent application of pesticides accumulates its concentration not only in soil, water, and sediment, but also in the food chain. The spread of pesticides by diffusion and dispersion has also posed the occupational health risk to the exposed inhabitants.

Despite the prohibition of some environmentally persistent (least biodegradable) pesticides (e.g., organochlorines), their uses are increasing in many countries.

A. Al-Mamun (✉)
Department of Civil and Architectural Engineering, Sultan Qaboos University, Muscat, Oman
e-mail: aalmamun@squ.edu.om

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Therefore, the benefits of pesticides use should be measured by considering the impacts of their persistence in the environment. Although the processes of degradation can eliminate pesticides to certain extents, it is accumulating toxic degraded compounds in the environment. Despite the extensive statistical data of pesticide degradations from regulatory agencies and testing organizations, it is still ambiguous to define the exact routes of pesticide degradation under a specific ground circumstances. Therefore, in this chapter we discuss the scientific contexts to pinpoint the pesticide degradation processes in the environment and their ultimate fate with the effects these pose to human and ecosystem.

2 Degradation Mechanisms of Pesticides in Environment

A pesticide is certified to apply only when it seems to be a non-persistent (i.e., degradation half-life should be few days to weeks) in the environment. After application, the majority of pesticides are adsorbed by targeted and non-targeted plants and species. The remaining fraction is degraded to by-products that are transported to other compartments of the environment [6]. Most of the pesticide degradation processes end with the formation of new toxic chemicals (residues) that have a chronic effect on the immediate inhabitants and ecosystems. All over the world, residues of many pesticides are identified in environmental samples from $ng{\cdot}L^{-1}$ to $mg{\cdot}L^{-1}$ concentrations. Recurrent investigations on the ground and processed drinking water in many parts of the world detect 15–20 types of pesticide degraded compounds in their highest permissible concentration (>0.1 $mg.L^{-1}$) [7, 8]. These unpleasant observations of the widespread pesticide persistence showed that approximately 50% of detected substances have long been prohibited to use, and 10–20% of the detected substances are the degraded compounds. These detected contaminants are not limited only in groundwater, but also in surface water, soil and sediments [9]. Recently, some pesticides and degraded compounds have been detected in high altitude regions, indicating their sufficient transport and persistence over hundreds of kilometers in the atmosphere [10]. Therefore, it is an urgent need to monitor the degradation of pesticides and their ultimate fate in order to control and clean them from the natural environment. This monitoring can improve the protection of the natural food and water sources.

The amount of pesticides to be transported from applied soil to other environmental compartments is determined by their chemical characteristics (volatility, solubility, and adsorption capacity), soil properties (porosity, clay content, and organic content), hydraulic loading, and crop management practices [11]. Degradation/transformation is the process of eliminating excess pesticides in the environment. It is a chemical or a bio-chemical process by which pesticides are transformed and broken down into less harmful chemicals that are bio-compatible to the environment [12–14]. But most of the pesticide degradation processes end with the formation of new toxic chemicals (residues) that have a chronic effect on the immediate inhabitants and ecosystems [11, 15]. Some of the degraded residues along with the non-degraded pesticides are most concerning chemicals in the environment as they are recurring back to human beings through bio-accumulation and bio-magnification.

The degradation of pesticides involves both biotic and abiotic processes. The biotic degradation is mediated by microorganisms or plants. The abiotic degradation, e.g., chemical and photochemical, is mediated by environmental agents, such as electromagnetic radiation, the presence of radical forming agents, temperature, acid and alkaline conditions. The governing degradation process for a specific pesticide is determined by its structural affinity to specific process, and the environmental conditions it is exposed (Fig. 1). For instance, redox gradients in soils, sediments, or aquifers often determine which biotic and/or abiotic degradations can occur. Similarly, photochemical transformations are restricted to compartments exposed to sunlight—e.g., the topmost meter(s) of lake or river water, the surface of plants, or submillimeter layers of soil. The atmospheric photo transformations strongly affect the chemical nature and transport potential of pesticides [16].

Pesticide degradation is not expected before the pest is controlled. Their degradation in the environment has been affected by a couple of soil parameters including pH [17, 18], temperature [13, 19–21], and moisture content [22]. The degradation processes are broadly categorized as microbial degradation (biodegradation), chemical degradation and photo-degradation [11, 23, 24].

2.1 Bio-degradation/Microbial Degradation

Microbial degradation is the dominant mechanism of pesticide degradation in soils [25]. It is a coincidence process during microbial metabolism. Soil microorganisms such as bacteria, actinomycetes, fungi, algae and protozoa use pesticides as a source of carbon and energy, or ingest them with other sources of food and energy. Approximately 100 million individual bacteria populations and 0.01 million fungi colonies live in 1 g of fertile soil with about 5 to 7 thousand of different species. These abundant diverged microorganisms in the soil make itself as an effective and eco-friendly bio-reactor to degrade toxic chemical wastes [26–29]. Such an enzyme bio-catalytic reaction ends with a variety of structural and toxicological modification into the parent pesticides [30, 31].

The exact pathways for bio-degradation of pesticides inside the microbial cells are still ambiguous. Numerous investigations in the recent decade have revealed that microorganisms use a specific genetic material (DNA bounded protein) to encrypt the necessary reactions to deal with a specific metabolic compound. Some other investigations have suggested that a specific group of microbes is responsible for specific substrate degradation [32, 33]. The dissolved pesticides in the soil solution transport across the cell membrane of the specific microbial colonies to be metabolized. Some other microbial extra-cellular enzymes predigest pesticides out of the cell that are poorly transported across the cell membrane. Once the pesticides enter into the microbial cell, it is metabolized via internal enzymes. The rate of biodegradation for

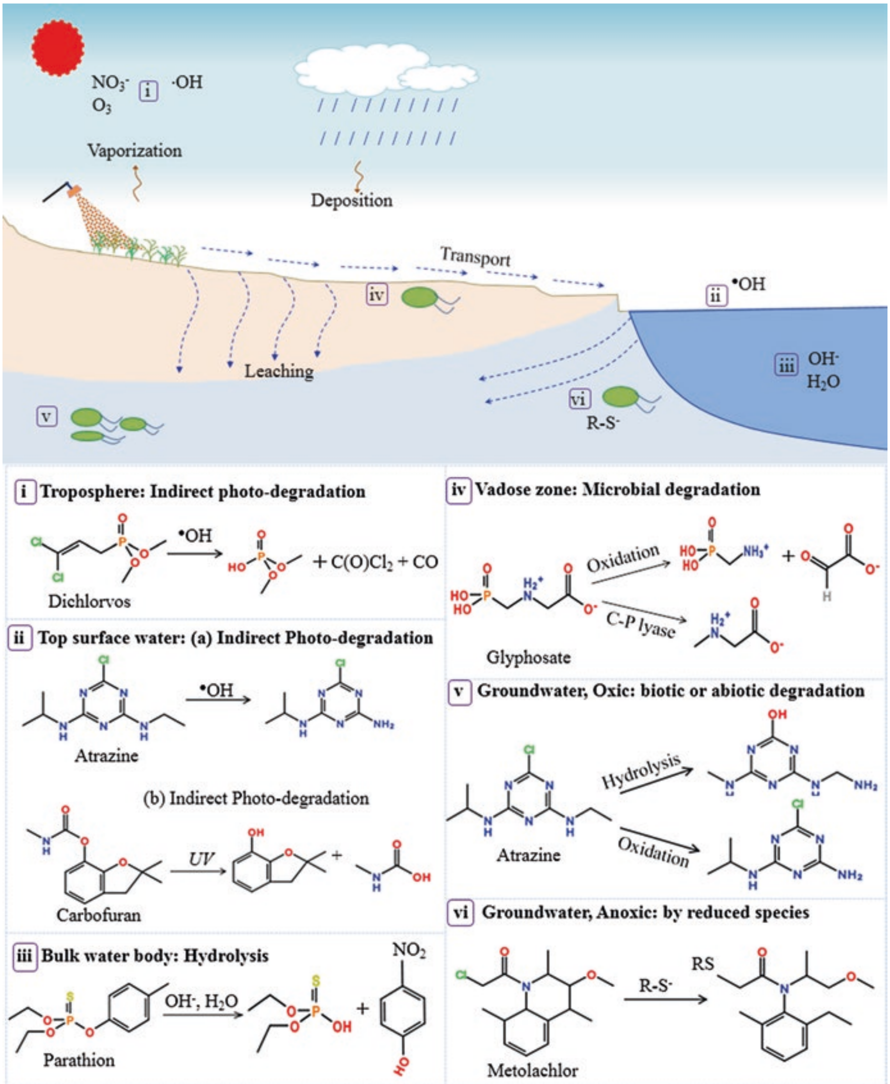


Fig. 1 Examples of pesticide degradation in the environment. (*Upper*) Examples of compartments and reaction partners in environment responsible for pesticide degradation. (*Lower*) Examples of relevant reactions in each compartment for some representative pesticides

a specific pesticide depends on the presence of necessary enzymes and the favorable environmental conditions to stimulate the bio-chemical reactions. Sufficient concentration of microbes, their diversity, and contact period between extra-cellular enzymes and pesticides are necessary for an efficient degradation process.

A number of mathematical models have been anticipated to represent the kinetics of the bio-degradation. Most of the models confirm either the first or the second order kinetics. However, in case of first-order kinetics, the rate of degradation is a function of temperature, pH, and limiting nutrients; while in case of second-order kinetics, the rate is a function of the available concentration of pesticides along with the size of bacteria populations [6, 34, 35]. The rate of biodegradation is also affected by some ground circumstances such as:

– Soil conditions (optimum pH, temperature, aeration level, moisture content, and organic content). The higher rate of biodegradation will be achieved at a high temperature, and moist soils with neutral pH.
– Crop alternating practice and frequency of the pesticide application (changing the groups of pesticides can maximize the potential for microbial degradation as well as pest resistance).

Some pesticide degradation, mainly hydrolysis, proceeds through both biotic and abiotic routes. But the higher rate of hydrolytic degradation is detected in the case of enzyme catalytic reactions. For instance, the abiotic dechlorination of atrazine to hydroxyl-atrazine in earlier days was observed as a slower process than the biotic (bacterial) degradation of atrazine with atrazine dechlorinating enzymes in recent studies. The recent investigations found the biodegradation following a second-order rate constant of 10^5 M^{-1} s^{-1} [36] (Fig. 1v). The statistical survey of atrazine dechlorination on topsoil and surface water revealed the abundance of genes that were encoded the atrazine dechlorination enzymes. Therefore, it is most likely the biodegradation of atrazine dominants in the environment. In case of biotic degradations, that have never been occurred abiotically, the rate of degradation is fairly depended on the activity of encoded enzymes. For example, glyphosate (herbicide) contains a C-P bond that is stable in strong electromagnetic radiation, acid or base, and other environmental conditions. The microbes that can break the C-P bond or metabolize it are widely spread in the environment (Fig. 1iv). The enzyme that catalyzed the C-P lysis reaction is encrypted by a 14-gene operon [37]. The pesticide compounds that do not have proper reactive groups are commonly degraded by chemical process. The rate of those chemical reactions depend on high pH and low-redox environments, as well as the in-situ formation of abiotic catalysts (e.g., poly-sulfides, surface-bound Fe(II), and MnO_2). These kinds of chemical transformation are sometimes mediated by microorganisms, which enhance the formation of abiotic catalysts.

2.2 *Chemical Degradation*

Chemical degradation is an abiotic process caused by the presence of environmental reactants and radicals (oxidizer, reducer, hydroxyl and hydrogen ions). The most usual chemical reactions that are involving in chemical degradations are hydrolysis, redox, and ionization. All of these common chemical degradation processes are affecting by the pH of the media [26, 38].

Hydrolysis Hydrolysis is the chemical reaction in which the functional groups of a pesticide compound is replaced by a hydroxyl radical or ion. As the hydrolytic reaction occurs only at the presence of OH^-, the rate of such reactions is mostly affecting by the pH of the pesticide containing media [38]. Such reactions modify the chemical structure of the complex pesticide compounds to make it simpler one. Depending on the substitution of specific groups, degraded products are usually less toxic than the parent chemicals. The predicted hydrolytic reactions for several pesticide compounds are listed in Fig. 1. Few investigations on abiotic hydrolysis of pesticides identified several functional groups that are more prone to replace by OH^- are organophosphates (Fig. 1iii), amides, carbamates, carboxylic acid esters, epoxides, carbonates, lactones, sulfonic acid esters, some halides (methyl bromide, propargyl), and many more [6, 39].

Some hydrolysis degradation has only been observed under a specific condition. An example of such degradations are clay-catalyzed triazine hydrolysis (Fig. 1v) [40], chloroacetanilide [41] and nitroaromatics transformation [38] in sulfidic environments (Fig. 1vi), or glyphosate oxidation by MnO_2 [42]. Hydrolysis has also been observed in groundwater or lake hypolimnions, which have longer hydraulic retention times (order of years) and lower biomass concentration due to almost complete removal of organic carbon by assimilation.

Redox (Oxidation-Reduction) Reaction Redox reaction consists of transferring electrons from the reduced ingredients to oxidized products. Some common pesticides show redox-degradation in the natural environments includes mercury, toxaphene, and DDT. The rate of redox reaction depends on the redox potential of the couple (oxidation/reduction), the number of electrons transfer, temperature, pH, and composition of metal ions present in the electrolytic media (soil and water). For instance, the reduction half-life of the organophosphorus insecticide (parathion) is on the order of minutes in a strong reducing environment [43]. The redox potential is the dominating factor to produce the oxidation state and final structure of the degraded product of pesticides in the environment. Not only the chemical degradation, but also the biodegradation is strongly influenced by the redox potential of the reaction. In this case microbes act as electron donors and/or acceptors, such as, oxidation of halogenated pesticides by methanotrophs, anoxic biodegradation with nitrate, reduction of halogenated compounds, and sequential aerobic/anaerobic degradation of halogenated organics.

Ionization The degradation of pesticides that are characterized either as organic acid or base is mostly determined by the concentration of H^+ in water within the environmental media. Similarly, the pesticides that are partitioning between liquid-gas and liquid-solid will be dominated by the acid-base interactions between the aqueous phase of chemicals and the liquid or gas concentration within the environmental media. The pesticides that are characterized as weak organic acids or bases do not have a significant influence in changing the pH of the environmental system. Therefore, the pH of the environmental media can be regulated whether the pesticide to be present as neutral or ionic forms [44]. The capacity of adsorption, dissolution, bioaccumulation, bio-persistent, and toxicity of a hydrophilic (extensively ionized) pesticides can be completely different from the pesticides that are characterized as weak acids or bases. For instance, the solubility of an ionic pesticide is likely be higher than that of the neutral species. Therefore, the ionized species could stay in water and has a low chance to be absorbed by the sediments. The ionized species can also change the pH of the environmental system. The approximate pH of the most aquatic systems ranged between 4 and 9, with extreme values lower than 2 and greater than 11.

2.3 Photo Degradation

Photo degradation is a process of breaking the chemical bonds in pesticide molecules by electromagnetic radiation (photon energy) coming from sunlight. It is possible on the surface of vegetation, topsoil (a sub millimeter), water (up to the depth of sunlight penetration), and in the atmosphere. Pesticides that are applied to the surface of vegetation and soil are more prone to photo degradation than pesticides that are incorporated into soil [11]. Photo degradation is taken place by the direct absorption of photon energy or by the radicles produced from other molecules that absorb photon energy. The second one is known as indirect photo degradation.

Direct photolysis has already been represented by first-order kinetics. The reaction rate of such kinetics is determined by the radiation energy needed to break the bonds and the intensity of available light. Light absorption bands for the molecules showed a little bit overlap for different pesticides in case of direct photolysis processes. However, such overlap is not affecting the degradation of pesticides except for trifluralin [45].

There are various photo-chemically active light absorbing agents are detected in surface water for indirect photolysis. Of them, dissolved organic matter (DOM), nitrate, and nitrite ions are important. DOM is the precursor of molecular oxygen, superoxide radical, and other radicals. Nitrate and nitrite ions produce hydroxyl radicals under irradiation. Therefore, the degradation rate of indirect photolysis depends on the concentrations of all relevant reactive species [46]. Such kinds of degradation is categorised by second-order kinetics.

All kinds of pesticide are subject to photolysis to some extents. Factors affecting pesticide photolysis are intensity of sunlight, time of exposure, the properties of the sites, the method of application, and the properties of pesticides. Chloroaromatics, aldehydes and ketones, etc., are more prone to photo degradation [47].

3 Fate of Pesticides in Environmental Media

Transport and leaching of pesticide pollutes surrounding air and water bodies, while adsorption by soil particles increases the chance of degradation and the risks of persistence in the environment (more than 1–6 months). Ecological toxicity and public health hazards are the two parameters to determine the effects of pesticide in the environment. Ecological toxicity is a cumulative measure of the negative impacts of pesticide through the entry into the food chain. The negative impacts are approximately measured by considering: (a) the reduced growth of zooplankton and phytoplankton in surface water; (b) the accumulation of carcinogens and neurotoxins that create reproductive and viability disorder in the offspring of the fish, amphibians, insects, invertebrates, and mammals; (c) the declining growth of beneficial organisms like pollinators; (d) the growth of drug-resistance to the disease causing pests and vectors (e.g., malaria, dengue and Chagas disease); and (e) the changes in biogeochemical cycles that interfere the growth and reproduction of aquatic and terrestrial macro and microorganisms. The public health hazards of pesticides are measured mostly by the acute toxicity caused to the immediately exposed populations or to the indirectly exposed populations through the contaminated air, water and food [48].

The risk of pesticides to contaminate surrounding environmental compartments (air, water and soil) is governed by the factors, such as the characteristics of the soil (porosity, bulk density, surface area, clay content, organic content, buffering capacity, and sorption capacity, etc.) and pesticide (volatility, solubility, stability, sensitivity to light, chemical structure, aliphatic and aromatic content, and chlorite content, etc.) [11, 49], method of application (dosage and form, e.g., granular, solution, suspension, powder or mixed with organic solvent), climatic conditions of the site (rainfall intensity, temperature, sunlight, humidity, etc.), and crop management practices [6]. The higher porosity of soil favors the leaching of pesticide from soil to waterbodies [25, 50]. Soil achieves higher sorption capacity with the higher contents of clay and organic [51]. The higher sorption capacity increases the risk of adhering pesticides with soil particles. This adhering of pesticides favors biodegradation by soil microbes [11]. The volatile pesticide can easily change its phase from liquid to gas which basically favors its movement through the air. The chemical structure and the aliphatic-aromatic contents of pesticide, as well as, the buffering capacity of soil determine the water solubility of pesticide compounds. Chemical structure also determines the rate of degradation of pesticide. The larger the molecular size with the higher contents of aliphatic and aromatic, the slower will be the rate degradation in the environment [52, 53].

During transformation processes, certain types of pesticides turn to harmless end-products for targeted and non-targeted organisms, and the ecosystem. However, some other types of pesticides transform into toxic end-products that are more dangerous than the parent chemicals. Some transformation processes reached to end with the change of chemical structure, which will alter the mode of transport of pesticide degraded-compounds in the environmental media [53]. The persistent xenobiotics, such as, metabolic end-products and non-degraded pesticides accumulate in the different components of the ecosystem, come to be a part of the soil humus, or come across the food chain leading to bio-magnification. Figure 2 shows the ultimate fate of non-degraded pesticides, degraded compounds and metabolic end-products into the different compartments of the ecosystem.

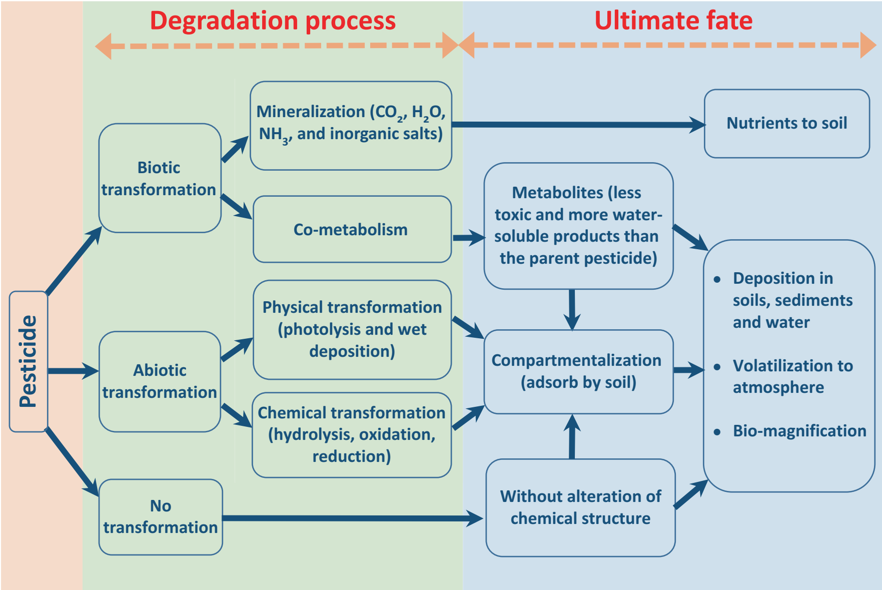


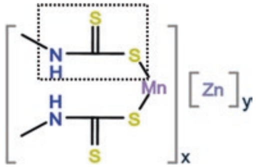
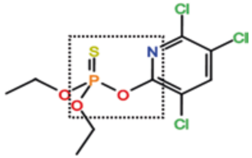
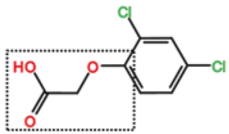
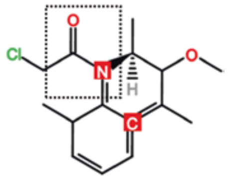
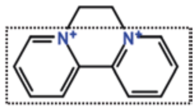
Fig. 2 Fate of pesticides and their degraded compounds in the environment

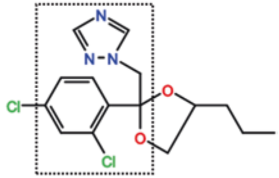
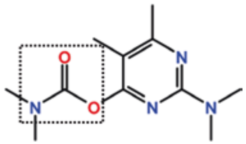
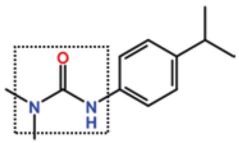
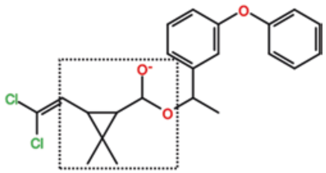
The ultimate fate of pesticides in the nature is mostly interrelated to the soil sorption capacity that determines not only their mode of transport, but also their availability to microbes [49]. The behavior of pesticides, their effective transformation (biotic and abiotic), and the risk of xenobiotics generation or persistence in the environment are subjective to the degradation kinetics and soil dynamics [54, 55]. The soils' dynamics that influence the rate of biodegradation are the moisture content and temperature, the physicochemical aspects, and the presence of other nitrogen and carbon sources, etc. This dynamic behavior of soil can entirely modify the microbial community and therefore, introduce a new microbial activity [49]. Table 1 summarizes the major pesticides' degradation routes with detected degraded compounds in the environment.

4 Reduction/Degradation of Pesticide Residue During Food Preparation

Generally the fresh and raw food ingredients need to be processed before table consumption. The processing techniques alter the fresh ingredients to value added products. Most of the food processing techniques help to reduce or completely eliminate the concentration of pesticide residues or insecticides on the surface or inside the food commodity. The common unit operations used to process the raw food commodities are washing, disinfecting, peeling, bleaching, parboiling and cooking.

Table 1 Top 10 pesticide classes, their major degradation pathways and persistence of the degraded compounds

Pesticide class	Utilization category	% in global utilization	Active representative group and structural formula	Possible environmental degradation routes	Persistence in environmental compartments (soil, water, sediments)
Dithiocarbamates (DTC)	Fungicides	7.1		Acid-catalysed hydrolysis; formation of potential NDMA[a] precursors [56]	Infrequently observed
Organophosphates	Insecticides	6.7		Microbial transformation (oxidation and hydrolysis)	Glyphosate and AMPA[a] frequently detected in groundwater [57–59]; chlorpyrifos, diazinon, disulfuton detected in rainwater and remote lake waters [60, 61]
Phenoxy alkanoic acids	Herbicides	4.7		Microbial transformation (oxidative dealkylation and aromatic ring cleavage)	Parent compounds frequently detected in groundwater [57, 58, 62]
Amides	Herbicides	4.2		Microbial transformation (hydrolysis and glutathione coupling)	Chloroacetanilides and their transformation products oxanilic (OXA) and ethanesulfonic acid (ESA) frequently detected in groundwater [57]; metolachlor and alachlor detected in remote lake waters [60, 61]
Bipyridyls	Herbicides	3.2		Only very slowly bio-transformed due to strong sorption to soil matrix	Rarely observed; mainly sorbed to sediments and soils

Triazines	Herbicides	2.3		Microbial transformation (oxidative dealkylation and hydrolysis)	Parent compounds and hydroxyl and dealkylated transformation products frequently detected in groundwater (significantly beyond phase-out period); atrazine and DEA[a] detected in remote lake waters [60, 61]
Triazoles, diazoles	Fungicides	2.0		Slow microbial transformation (oxidation); photo transformation of specific representatives	Flutriafol detected in remote lake waters [61]
Carbamates	Insecticides/ herbicides	2.0		Ready microbial or base-catalyzed transformation (hydrolysis of ester bond); photo transformation of specific representatives	Rarely observed
Urea derivatives	Herbicides	1.7		Microbial transformation (oxidative dealkylation and hydrolysis)	Parent compounds frequently detected in groundwater [57, 58]
Pyrethroids	Insecticides	1.3		Microbial transformation (hydrolysis, oxidation); photo transformation (direct and indirect)	Rarely observed; mainly sorbed to sediments and soils

Values are based on amounts used relative to total global pesticide consumption in 2009/2010 [2]
[a]*AMPA* aminomethylphosphonic acid, *DEA* desethylatrazine; *NDMA* N-nitrosodimethylamin

Table 2 Examples of the effects of food processing techniques on pesticide residue dissipation

Processing	Food ingredients	Pesticide	Residue dissipation	Reasons	Reference
Washing (30 s)	Bitter grounds	Endosulfan	59%	Micro particles of pesticide on the surface of food ingredients are easily washed by stirring of water	[63, 64]
Washing (twice)	Soybeans	Dichlorvos	80–90%		[64]
Washing	Golden apple	Phosalone	30–50%	Reduction due to dissolution of pesticide in water or solution. Removal efficiency of washing depends on location of residue, age of residue, water solubility and temperature	[65]
Washing (Vinegar)	Tomatoes	HCB p,p-DDT Dimethoate	51% 34% 91%		[66, 67]
Washing (10% NaCl solution)		HCB p,p-DDT Dimethoate	43% 27% 91%		
Tap water washing		HCB p,p-DDT Dimethoate	9.6% 9.2% 19%		
Peeling	Bitter gourds Mango	Endosulfan Fenthion Dimethoate	84% 100% 100%	Peeling off fruit skin removed all residues, which are accumulated on pericarp	[63]
Parboiling	Rough rice	Malathion	99.99%	Inactivation or degradation of pesticide at high temperature	[68]
Cooking (10 min open cooking, 10 min steam cooking)	Bitter gourds	Endosulfan	63–68%	Increase volatilization and hydrolysis or other chemical degradation at high temperature, thus reduce residue level	[63]

Each operation collectively reduces the concentration of the pesticides present in food commodities. All most all the loose surface residues and polar chemicals are eliminated by washing. A significant portion of non-persistent chemicals are hydrolysed and bleached out by hot water washing. Non-polar chemicals (chlorinated hydrocarbons) are grimly detained in the waxy layers of the fruits and vegetables. Peeling of fruits and vegetables completely removes the pesticide residues accumulated in waxy layers, however this process reduces the beneficial phytochemicals in fruits and vegetables. Table 2 summarizes the common food processing techniques along with their degree of residue removal from processed foods.

5 Conclusions

Pesticides are extensively applied to achieve higher agriculture production. However, less attention has been paid to their potential harmful impacts on environment and ecosystem. Majority of the pesticides are persistent organic pollutants.

They are vastly stable in the environment and accumulative in ecological objects (e.g., organisms and food chains). Some of them have rapid toxicity to humans and animals; others have chronic effects on reproductive, immune and endocrine systems. Pesticides and their derivatives are also carcinogenic and transported through the environmental compartments over a longer distances from the points of application.

There are many physical and bio-chemical processes influence the transportation and degradation of pesticides. Pesticides and their residues are altered and eliminated by the food processing techniques before ingestion. All those processes collectively determine the ultimate fate of the pesticides in the environment. The ultimate fate is also affected by the site characteristics (e.g., soil porosity, sorption, organic contents, etc.), environmental conditions (e.g., temperature, pH, presence of oxygen or electron acceptors, and nutrients), crop management systems, and chemical handling practices. That's why; the understanding of fate can ensure the safe and effective application of pesticides into the environment.

Future knowledge in this field should address to improve the ability of predicting the long-term fate of pesticides, understand their degradation at threshold concentrations and in low-nutrient environments (e.g., groundwater, lake hypolimnions, and seawater). The development of such knowledge will need innovative way of characterizing the degradation procedures by using advanced analytical tools (e.g., compound-specific isotope analysis, enantiomer analysis, and mass spectrometry) to identify the degraded products. Also, the developments of bioinformatics to understand the functions of proteins by DNA sequences are expected to apply.

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Health Concerns of Pesticides

Mrittika Debnath and Mohidus Samad Khan

1 Introduction

In modern agriculture, pesticides are one of the major components for maintaining steady crop production. According to the Food and Agricultural Organization (FAO) of the United Nations, pesticides are substances or mixture of substances, intended for preventing, destroying or controlling any pest causing harm during or otherwise interfering with the production, processing, storage, transport or marketing of food, and agricultural commodities. Pesticides are designed to control pests, weeds, and other plant pathogens; however, their mode of action is often nonspecific due to the presence of heterogeneous chemicals [1]. Pesticides often kill or harm organisms other than pests, including humans. Because of the improper and irrational use of different types of pesticides, the environment as well as the food chain (e.g. vegetables and fruits) may get contaminated with these chemical substances [2]. Individuals could exposed to pesticides or pesticide residues either through workplace or due to environmental contamination. Based on the level of contamination, these residues can affect different parts of the human body.

Individuals' reaction to pesticides varies with their level of sensitivity and immunity. For example, some people may show no reaction to an exposure of a specific pesticide, whereas it may cause severe illness to others [3]. Therefore, it is important to identify and assess the detrimental or negative effects 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 [4].

M. Debnath
Department of Chemistry and Biochemistry, Northern Illinois University, DeKalb, IL, USA

M.S. Khan (✉)
Department of Chemical Engineering, Bangladesh University of Engineering and Technology (BUET), Dhaka 1000, Bangladesh
e-mail: mohid@che.buet.ac.bd

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This article discusses the types and applications of pesticides, the acute and chronic effects of pesticides on human health, the intentional and unintentional ways of exposure to pesticides, and the immediate measures that should be taken after pesticides poisoning. This article also highlights the possible measures that should be taken when selling pesticides, and while applying pesticides at home or work place.

2 Health Effects of Different Types of Pesticides

On the basis of chemical structure, working principle, target molecules, and possible health effects, pesticides can be broadly classified as organochlorine pesticides, organophosphorous pesticides, carbamates, pyrithroids pesticides, biorational pesticides, and microbial pesticides [5]. The health effects of various pesticides are discussed in the following sections.

2.1 Organochlorine Pesticides

These pesticides are persistent organic pollutants (POPs), a class of chemicals that dissociate slowly in the environment, and accumulate in the fatty tissues of animals [6]. Hence, POPs stay in the environment and food web long after being applied [6]. Many POPs are endocrine disrupting chemicals, which can create subtle toxic effects on the hormonal system of the animal body [7]. Endocrine disrupting chemicals often mimic the natural hormones of the human body, disrupting the normal functions, and causing to adverse health effects [8].

Among its wide variations, the mostly used organochlorine pesticides are dichloro-diphenyl-trichloro-ethane (DDT) and its derivatives, such as hexachlorocyclohexane (HCH), aldrin and dieldrin. These POPs are widely used in many countries because of their low cost and versatility against pests. Due to their potential bioaccumulation and biological effects, these POPs have been already banned in different countries [9]; however, POPs are still available in the natural ecosystem [10]. Some of the names and related health effects of Organochlorine Pesticides are listed in Table 1 [4, 11–17].

2.2 Organophosphate Pesticides

Organophosphates (OPs) are produced from the reaction between phosphoric acid and alcohols. These substances are highly toxic in nature. Upon entering the body through ingestion, inhalation, or contact with skin, OPs may affect the human nervous system. OPs can also cause irreversible blockage leading to accumulation of

Table 1 Health effect of organochloride pesticides

Name	Health effect
1. BHC and its derivatives	Can harm the nervous system, β BHC alters thyroid hormone levels and can affect brain development; may cause cancer. [11], photosensativity, permanent hair loss [4]
2. α and ϒ Chlordane	Inhalation or ingestion may cause toxic effects, such as headaches, depression, anxiety, poor balance, tremors, and mental confusion; may cause cancer in animals [12]
3. Endosulfan 1, 2 and sulfate	Acutely neuro toxic; acute poisoning include hyperactivity, tremors, convulsions, lack of coordination, staggering, breathing, nausea and vomiting, diarrhea, and in severe cases, unconsciousness (Agency of Toxic Substances, 2013) [13]
4. DDD, DDE, DDT and their derivatives	May cause pancreatic cancer, non-Hodgkin's lymphoma, breast cancer, leukemia, skin sensitization, allergic reaction and rash [14], affect nervous system, cause prickling sensation of the mouth, nausea, dizziness, confusion, headache, lethargy, incoordination, vomiting, fatigue, and tremors; causes reproductive problems in rats and birds [15]
5. Aldrin and Dieldrin	Decreases the effectiveness of immune system, increase infant mortality, reduces reproductive success, causes cancer, birth, and kidney problem [16]
6. Endrin, Endrin aldehyde and Endrin ketone	Swallowing large amounts may cause convulsions, and lead to death within a few minutes or hours; less serious exposure result in headaches, dizziness, confusion, nervousness, nausea, vomiting [17]

the enzyme (cholinesterase), which results in fasciculation of muscles [18]. Some of the OPs are lipophilic, such as chloropyrifos, diazinon, parathion, and coumaphos, which can accumulate in body fat, and remain in the body for many days [19].

In humans, poisoning symptoms may include excessive sweating, salivation and lachrimation, nausea, vomiting, diarrhea, abdominal cramp, general weakness, headache, poor concentration and tremors. In serious cases, respiratory failure and death can occur. Even after several weeks of exposure, organophosphate induced delayed neuropathy (OPIDN) (i.e. nerve damage) may begin with burning and tingling sensations and progress to paralysis of the lower limbs [20]. Key health effects of OPs are:

Psychiatric effect Exposure to agricultural use of OPs causes depression, a major risk factor in suicides [21]. Researchers have found that suicide rates are higher in areas of greater OPs use [22].

Cardiac effects A number of studies have drawn attention to cardiac effects associated with occupational exposure to OPs [20]. Researchers have mentioned that OP exposer can cause slowing of the heart with decreased cardiac output [20] .

Eye defect Exposure to OPs during agricultural activities is related to an increased incidence of myopia (short-sightedness), and a more advanced ocular disease syndrome (Saku disease) [23].

2.3 Carbamate

Unlike organophosphates, carbamates are not structurally complex. Carbamates are applied either as powder or sprays. Carbamates may be absorbed through the skin, ingestion and/or inhalation. The immediate toxic effect of carbamates is very similar to that of organophosphates [24]. The short-term exposure of carbamate pesticides can cause muscle twitching, headache, nausea, dizziness, loss of memory, weakness, slow down heartbeat, tremor, diarrhea, sweating, salivation, tearing, and constriction of pupils. Long-term exposure of the carbamate can cause delayed neurotoxicity, such as tingling and burning in the extremities. This delayed neurotoxicity can progress to paralysis, which is seldom reversible. It may damage the liver, kidney, immune system, and bone marrow. Some carbamates are suspected carcinogens [25].

Carbamates insecticides act similarly on the nervous system, but have a shorter duration of action. Like OPs, they can affect the nervous system by inactivating the enzyme acetylcholinesterase [26]. Commonly used cabamates include aldicarb, carbofuran, carbaryl, ethienocarb, fenobucarb, oxamyl, and methomyl. These pesticides are widely used, and showed varying degrees of toxicity.

2.4 Pyrethroid Pesticides

Pyrethroid pesticides are potent neuro poisons, endocrine disruptors, and may cause paralysis [27, 28]. Pyrethroids are a synthetic version of pyrethrin, a natural insecticide, and are more stable in sunlight than pyrethrins. Pyrethroid pesticides are popular insecticides as they can easily pass through the exoskeleton of the insect. Deltamethrin and cypermethrin are the examples of pyrethroid pesticides [5].

2.5 Biorationals (Biorational Pesticides or Biopesticides)

Biorational or biopesticides are considered as relatively non-toxic to humans and environmentally safe. The EPA defines biorationals as “certain types of pesticides derived from such natural materials as animals, plants, bacteria, and certain minerals” [5]. The effect of biopesticides depends on the interruption of natural growth processes of arthropods. They do not selectively attack any arthropod species, but generally have extremely low toxicity for vertebrates, including people. This group includes insect growth regulators (IGRs), chitin inhibitors, plant growth regulators, and chromosterilants [5].

2.6 *Microbial Pesticides*

Microbial pesticides kill arthropods either by releasing toxins or infections through microbial organisms. Two common microbial pesticides that fit are *Bacillus thuringiensis serotype israelensis* (Bti) bacteria and *Bacillus sphaericus* (Bs) bacteria [29]. Products from these bacteria are used to kill mosquito larvae; Bti also kills black fly larvae. Most microbial pesticides are more selective than biochemical pesticides [5]. The organisms used in microbial insecticides offer greater safety since they are nontoxic and nonpathogenic to wildlife, humans and other organisms. [30]

3 Mode of Exposure to Pesticides

The effect of pesticides on human body can be determined from the mode of exposures. Exposure to pesticides can occur in different ways and in different degrees. Figure 1 demonstrates classifications of pesticide exposure to the human body [4].

3.1 *Unintentional Exposure*

Unintentional exposure to pesticides through environmental contamination or work place is a common phenomenon [1]. The modes of unintentional exposure to pesticides can be broadly classified as occupational and non-occupational exposures.

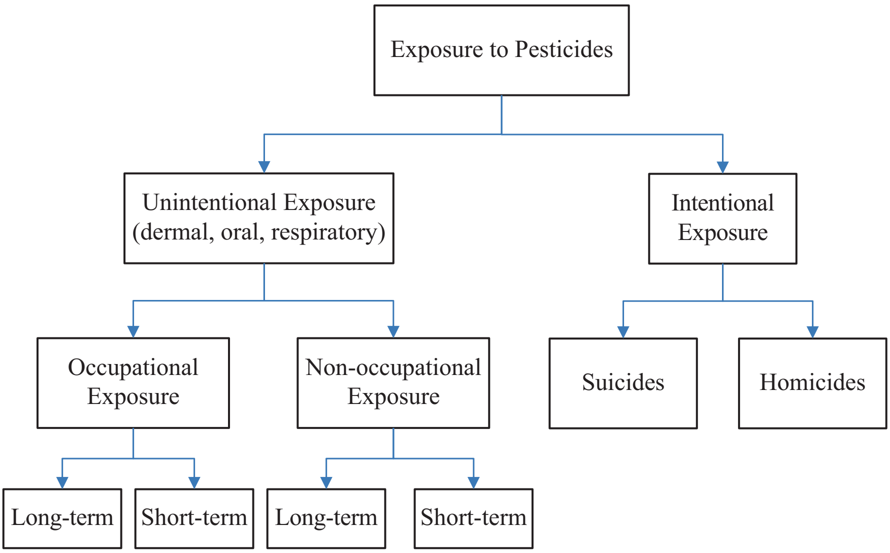

Fig. 1 Classifications of pesticide exposure to the human body [4]

3.1.1 Occupational Exposure

Workers involved in the agriculture sector, pesticide manufacturing industries, and other relevant sectors can easily get exposed to pesticides in their workplaces. In particular those who handle pesticides directly are at extremely high risks of exposure. Most occupational exposures to pesticides occur through inhalation or dermal contact, and in some cases through ocular exposure [31].

Agricultural workers Farmers directly or indirectly become exposed to pesticides during agricultural practices, and in the process of producing different kinds of crops, vegetables, and fruits. The possible ways agricultural workers may get exposed to pesticides are:

- by directly applying pesticides [32].
- by transporting, loading, and mixing pesticides [32].
- from accidental spills of chemicals, leakage, or faulty equipment [31]
- weather conditions at the time of application, such as air temperature and humidity, which may affect the volatility of the product, and the perspiration rate of the human body [33]
- by working close to pesticides applicators [34].

Furthermore, the frequent and long term handling of pesticides affects the human health. The exposure of an individual farmer who applies a pesticide once a year is lower than that of a commercial applicator, who typically applies pesticides for consecutive days or weeks during a particular season [33]. Several studies reported that agricultural workers suffer from eye burning, neurological effects, lever effects, and skin damages because of short term exposure to pesticides [4]. The genotoxicity of pesticides has been found positive in many agriculturists based on their exposure time and types of pesticides they use. For example, a study conducted on the agricultural workers employed at the Agronomic Institute of Brazil showed that there was a significant increase of chromosomal aberrations or damage (CA) frequency, in spite of using preventive measures [35].

Pesticides manufacturers Pesticides manufacturers are often in direct contact with pesticides. The workers working in the pesticide manufacturing units are directly exposed to the chemicals; employees working in the other units of pesticide manufacturing industries may also get exposed to pesticides directly and/or indirectly. Therefore, workers in the non-production units of these industries also face similar risky situations like the individuals who are exposed to pesticides on an agriculture farms [31].

Exterminators who use pesticides Exterminators, who apply pesticides and control termites at residential areas and public places, are another major group of workers who can get exposed to organophosphates [36]. A survey on pesticide applicators who had worked for a median of 1.8 years applying organophosphates against termites and other pests in the state of North Carolina, USA, showed that the average urinary chlorpyrifos metabolite of the recently exposed applicators (629.5 mg/L) was far higher than that of the general population in USA (4.5 mg/L) [37].

Greenhouse workers and florists Pesticide exposure is also known among the greenhouse workers and florists. Their work includes the use of pesticides on flowers, other plants, and foliage. Fumigant pesticides can be a cause of potential health risk to the employees of greenhouses [31].

3.1.2 Non Occupational Exposure

Environmental or non-occupational exposure to pesticides in individuals occurs in places where the exposure to pesticides is not a result of the occupation [38]. A number of the non-occupational exposure situations are briefly discussed in the following sections.

Residential exposure Domestic use of pesticides is common among the urban and rural dwellers. A report states that 80 to 90 per cent of USA households use pesticides for various applications [39]. Organophosphate insecticides are used for killing bugs in and around the house and in the garden where exposure to organophosphate can easily occur [40].

Close proximity to agricultural farms Exposure can often occur when pesticides applied at agricultural farms drift to surrounding areas where general people live. This form of exposure is known as the "farm proximity pathway" [33]. The nearby residents' exposure may not be as acute as it is among agricultural workers; however, their proximity to an organophosphate source still puts them at risk.

Aerial spraying The extensive spraying of pesticides from aircraft over residential areas can be a source of exposure in the general population, if the residents of the sprayed areas breathe in the air that contains airborne pesticides [32].

Exposure in public places Exposure to pesticides in public places is an unexpected, unintentional, non-occupational form of exposure [36]. For example, people can be exposed to organophosphate insecticides applied by exterminators in common places like public restrooms, restaurants, hotels, schools, churches, business offices, apartment buildings, grocery stores, and hospitals.

Pesticides in food and water Pesticide residues can be found in fruits, vegetables, and other crops due to the irrational use of pesticides during cultivation. Agricultural washed water containing pesticide residues may enter into water streams close to the agricultural fields, and eventually the pesticide residue may affect fishes and other living organism in the water reservoir [41]. It is reported that the pesticide residue concentration found in food and water bodies is low, however, regular accumulation in human body, especially when it exceeds the Maximum Residual Level (MRL), may cause harm to human body [42].

3.2 Intentional Exposure

Under exceptional circumstances, such as committing suicide, individuals may expose themselves to pesticides intentionally. The main route of exposure is ingestion [4]. The victims may use pesticides to harm themselves because of the availability of pesticides. Often farmers keep their own supply of pesticides, commonly within, or close to, the households which makes an easy access to pesticides for other people [43]. In some cases, the damage caused by the pesticides to human body is fast and irreversible, which allows very limited time to rescue the victim exposed to pesticides (e.g. parathion). Thus the occurrence of fatal intentional exposures increases.

The pattern of using pesticide is also an important issue. When two or more pesticides used simultaneously, they become more toxic (e.g. heptachlor and lindane) or less toxic (antagonism) [4]. Interactions of dietary nitrite with pesticides that contains secondary amine group can result in the formation of nitrosamines, which may be more toxic, mutagenic, or carcinogenic [44].

4 Effects of Pesticides on Human Health

The toxic effects of pesticides on human health can be of various forms, such as: headache, coma, and convulsions to even death [45]. While some of the effects are irreversible, others can be made reversible in long term. The effects of pesticides can be cured with prompt medical treatment. However, based on the degree of toxicity, the effects on human health can be broadly classified into two groups: acute or short term effects, and chronic or long term effects.

4.1 Acute or Short Term Effects

"Acute effects" of pesticides on human health can be defined as *the harmful effects that occur from a single exposure by any route of entry*. The exposure to acute toxicity can occur through different routes such as: dermal (skin), inhalation (lungs), oral (mouth), and eyes [45]. The principle toxic effect is the inhibition of cholinesterases in the blood and nervous system, which prevents degradation of acetylcholine at the neuronal synapses, resulting over activity of the cholinergic neurons [46].

Some acute and sub-acute toxic effects include irritation, burning, stinging and itching, rashes and blisters on the nose, throat, and skin, nausea, dizziness, diarrhea, headache, impaired cognition, blurred vision, proximal muscle weakness, and seizures. The initial symptoms may not be severe enough to seek for immediate medical attention for an individual. However, treatments should be prescribed if someone is exposed to pesticides [47].

Acute toxicity is determined by examining the dermal toxicity, inhalation toxicity, oral and eye toxicity, and skin irritation under controlled laboratory conditions. The laboratory test is often based on measuring the amount of pesticide required to kill 50 percent of the animals in a test population, which is expressed in terms of LD_{50} (lethal dose 50) or the LC_{50} (lethal concentration 50). The LD_{50} and LC_{50} values are determined based on a single dosage and are recorded in milligrams of pesticide per kilogram of body weight (mg/kg) of the test animal or in parts per million (ppm). LD_{50} and LC_{50} values are useful in comparing the toxicities of different active ingredients and different formulations containing the same active ingredient. The lower the LD_{50} or LC_{50} value of a pesticide product, the greater its toxicity to humans and animals [45].

4.2 Chronic or Long Term Effects

Any harmful effect that occurs from small doses repeated over a period of time is termed as "chronic effects". Chronic effects of pesticides may not appear for weeks, months, or even years after exposure; but later, when it starts showing its impacts, it becomes difficult to connect relevant health impacts to pesticides exposure [47]. The chronic toxicity of a pesticide is more difficult to determine than acute toxicity analysis. LOEC (lowest observed effect concentration), NOEC (no observed effect concentration), and EC_{50} (half maximum effective concentration) are some of the approaches for measuring chronic toxicity. Chronic health effects due to pesticide exposure include neurologic, carcinogenic, pulmonary, and reproductive effects.

4.2.1 Neurologic Effects

From recent studies it is becoming increasingly apparent that chronic occupational exposure to a variety of pesticides can cause mild to severe deterioration in neurologic function that may be irreversible [48]. Chronic neurologic effects have been associated with exposures to organophosphate, organochlorine, and carbamate insecticides, a variety of fungicides (such as: tnercurials, diphenyl, hexachlorobenzene, hexachlorophene) and fumigants (such as: methyl bromide, carbon disulfide, sulfuryl fluoride) [48]. Agricultural workers are the primary victims of these effects since these pesticides are used in agricultural purposes. The commonly reported chronic neurological effects include lethargy, fatigue, headache, hyperirritability, dizziness, muscle tremor, twitching, jerks, weakness, paralysis, paresthesias, polvneuropathy, incoordination, visual disturbance, central nervous system impairment, loss of memory, forgetfulness, confusion, altered sleep, slurred speech, impaired motor skill, altered behavior, nervousness, psychiatric symptoms, nervousness, agitation, and Parkinson like syndrome [46].

4.2.2 Carcinogenic Effects

Several studies have shown that exposure to pesticides may impose a potentially serious cancer risk to the general population [49]. Types of cancer that are associated with pesticides exposure include soft tissue sarcoma and lymphoma, non-Hodgin's lymphoma, soft tissue sarcoma leukemia, lung carcinoma, and ovarian carcinoma. A survey conducted by the National Toxic Forum reported that 28 out of 47 pesticides are suspected as being carcinogenic [49]. In addition, cancer related to hematopoietic system have been observed among workers with significant pesticide exposures [50]. However, the available data are insufficient to estimate the rate of pesticide-related cancer for the general population [50].

4.2.3 Pulmonary Effects

Chronic respiratory impairment has been found in workers with many years of exposure to organochlorine and organophosphate insecticides. Some of the pulmonary effects are persistent pulmonary fibrosis, chronic cough, and bronchiolitis obliterans. [51].

4.2.4 Reproductive and Developmental Effects

Many pesticides are known to have reproductive effects [47]. Agricultural workers appear to be associated with specific morphologic abnormalities in sperm. Several studies suggest that parental employment in agriculture could increase the risk of congenital malformations in offsprings, particularly orofacial cleft. Miscarriage, infant prematurity, and congenital malformations have been detected in female floriculture workers exposed to pesticides. [52].

4.3 Health Condition of Individuals

The impact of pesticides may vary with health condition of the affected person. It has been seen that children are more vulnerable to immunological, developmental, and neurological symptoms from pesticides than adults. The higher rate of cell division, respiration, and developing organs, nervous and immune systems of the children increase their susceptibility to pesticides attack [52]. In particular, exposure to neurotoxins at levels that would be safe for adults may cause permanent loss of brain function in infants and toddlers. Certain pesticides, such as pyrethrin/pyrethroid, organophosphate, and carbamate may severely affect asthma patiens [53].

5 Recommendations

The key reasons behind the health effects caused by pesticides are the lack of proper knowledge and awareness of pesticide use, absence of legislative enforcement, and uncontrolled sale of toxic pesticides in open markets [4]. Compliance with available standard guidelines for the safe use of pesticides, and cautious measures during selling and storing pesticides can minimize most of the hazards related to pesticide exposure.

5.1 Measures During Selling

The manufacturer, the formulator, or the person responsible for labeling and registering the pesticides with national authority should ensure proper labelling written in local language with comprehensive instructions for safe use, and warning for possible hazards. The label should additionally specify the ingredients, and also provide instructions for first aid in case of poisoning [4].

5.2 Measures During Applying Pesticides

Users should follow the instructions provided in the label of the container or packaging before using pesticides. The users and producers should use personal protective equipment, such as protective clothing made of butyl rubber, PVC, neoprene, laminated poly ethylene fabrics, gloves, eye protectors and masks to prevent the risk of personal hazard [54].

5.2.1 Pesticides Applied in Agriculture

The Integrated Crop Management (ICM) includes guidelines to be followed by the farmer unions to enforce actions for the production of safe agricultural products without contaminating the environment [55]. For pest control, the ICM encourages the use of complementary methods of pest management to reduce animal pests or weed population below its economic injury level, and to minimize pesticide impacts on the other components of the agro-ecosystem. Pest resistant crops against insects and fungi, biological control, and other cultural or physical measures can be used as complementary methods. Pesticide applications on crops should include the following information [55]:

(a) identify the appropriate pesticide for the specific pest attack the plants or crops,
(b) use of pesticide at the recommended dose when a pest is found or it requires a precautionary treatment,

(c) optimization of pesticide use for economic saving through adjusted doses according to pest population density, and
(d) minimization of pesticide use by altering the cultivation system to lower the risk of pests.

To ensure the safety of agricultural workers, pesticide handlers and cultivators, US EPA activated the Worker Protection on Standard (WPS) in 1995 [56]. The aim of the WPS regulation is to "minimize pesticide exposure, mitigate the exposure that occur and inform agricultural workers about the hazards of pesticides". It requires the agricultural employers to notify the workers about the pesticide treatments and advances. WPS also offers basic pesticides training, provides personal protective equipment, and supplies the affected worker and medical personnel with proper information [56].

5.2.2 Pesticides Applied at Home and Work Place

According to a study conducted by EPA, around 85% of the total daily exposure to airborne pesticides comes from breathing air inside the home [57]. Improper pesticides applications should be avoided at homes and offices. For any pest related issue, alternative measures, such as temperature treatment, biological controls, and least toxic baits should be applied. Spraying pesticides in lawns and gardens should be avoided [57].

5.3 Measures After Pesticides Poisoning

The chemicals of pesticides may injure humans in many ways. It is therefore, important to take appropriate measures if pesticide poisoning or exposure occurs beyond the permitted limits. In case of any pesticides poisoning, could occur, the following steps may be followed [58–61].

Seek for medical assistance In any pesticide poisoning, the first thing is to avoid further contamination, and to ensure that the victim is breathing. There is a good chance of recovery if proper oxygen supply to the body can be maintained. Following this, medical assistance should be sought [58].

Measures during direct pesticides exposure Emergency treatments depend on type of exposure. It has been mentioned before that pesticides can enter in our body in one of three route of exposure: dermal (absorption through the skin or eyes); respiratory (inhalation through the lungs); or oral (ingestion by mouth). Measures during any kind of exposure are discussed below:

(a) **Measures in case of swallowing pesticides:** If someone swallows pesticides, the victim should be treated immediately. Firstly, the label of pesticides has to be identified. There are two ways that can be used to help out the victim in case of swallowing poison: either (1) inducing vomiting or (2) diluting the poison by having the victim drink milk or water [59].

Inducing vomiting is the quickest way to get the pesticides out of stomach, however, it may not be effective in certain cases like

– when the victim is unconscious
– when the pesticides is highly corrosive or highly concentrated petroleum product.

(b) **Measures when skin and eyes get exposed to pesticides:** If the skin directly get exposed to pesticides, it is advised to wash off the pesticides immediately to prevent further exposure and followed by drenching the skin with soap and water carefully. In case of chemical burning, cold running water should be used to wash the skin. The affected area then need to be covered loosely with clean soft clothes. Further treatment should be carried out based on medical advisory [60].

In case of eye injury, eyes should be washed with clean water immediately for around 15 min since eye membrane can absorb pesticides faster than any other external part of the body. Eye lids should be kept open while washing with a gentle stream water and using any kind of drugs or eye drops are prohibited [58, 61].

(c) **Measures in case of inhaling pesticide:** The victim need to take fresh air immediately after inhaling pesticides. Artificial respirator should be used while shifting the victim, and also when the victim suffers from breathlessness. Victim should be kept as quiet as possible. Tight clothing should be loosened. If the victim is getting unconscious, he should be protected from getting fall and his chin should be pulled forward to ensure proper air flow [58, 60].

5.4 Development of Techniques for Exposure Assessments

Bio-markers are of great importance in case of determining any biological action of pesticides, like DNA or RNA damage or any change of gene expressions, which are eventually related to the exposure to pesticides. Extensive research should be conducted to develop reliable bio-markers as predictors of subsequent health outcomes. Besides, studies should be continued to improve the existing methods of exposure assessment, and to reduce the health risk from pesticides poisoning [52].

6 Conclusion

Pesticides play an important role in producing reliable supplies of agricultural produce at affordable prices to consumers, improving the quality of produce, and ensuring high profits to farmers. Although pesticides are developed to function with reasonable certainty and minimal risk to human health and the environment, many studies have raised concerns about health risks from occupational and non-occupational exposures to pesticides and pesticide residues. 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 [62].

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Methods of Pesticide Residues Reduction in Grains

Geetanjali Kaushik, Arvind Chel, and Ashish Gadekar

1 Introduction: Food Safety and Quality Concerns

Over the last few years, food safety and quality issues have caused considerable concern among the consumers and law enforcing authorities. Incidents of food contaminants with pesticide residues, colors, chemical preservatives, and toxins, are on the rise and have resulted in significant mortality and morbidity among populations particularly in the developing countries. In this regard, it is important to first discuss food safety. *"Food safety" implies absence or safe levels of contaminants, adulterants, naturally occurring toxins or any other substance that may result food harmful on an acute or chronic basis*. Food safety therefore relates to the harmful microorganisms, and various chemicals in food. The microbiological elements include food borne pathogens like Salmonella, Campylobacter, E. Coli O157, Rotavirus, Protozoan Cryptosporidium, and Mycotoxins which cause incidences of food poisoning. The chemical contaminants in food include pesticide residues, heavy metals (such as Hg, Pb) and the various food preservatives and colors. Other food contaminants refer to the veterinary residues and genetically modified organisms (GMOs) [49]. Widespread contamination of food commodities

G. Kaushik (✉)
Institute of Management, Mahatma Gandhi Mission N-6, CIDCO Aurangabad, Aurangabad, Maharashtra, India

Department of Civil Engineering, JNEC, Mahatma Gandhi Mission N-6, CIDCO Aurangabad, Aurangabad, Maharashtra, India
e-mail: geetanjalikaushik2007@gmail.com

A. Chel
Department of Mechanical Engineering, JNEC, Mahatma Gandhi Mission N-6, CIDCO Aurangabad, Aurangabad, Maharashtra, India

A. Gadekar
Institute of Management, Mahatma Gandhi Mission N-6, CIDCO Aurangabad, Aurangabad, Maharashtra, India

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with harmful chemical compounds has reaffirmed the significance of safe and high quality food products [40, 46]. Food contamination can occur inadvertently due to direct (i.e. use of chemical pesticides to control the agricultural pests at different stages of crop production) or indirect (i.e. use of pesticides and chemicals during storage or food processing) exposure to toxic chemicals [12]. Hence, a sustainable solution to this scenario of unsafe and poor quality food warrants a paradigm shift in the current mindset.

2 The Need of Paradigm Shift

Dietary surveys reveal that diet of the significant population in the world is based on a cereal grain and legume. The supplementation of cereal-based diets with legumes improves overall nutritional status and is one of the best solutions to tackle protein-energy malnutrition prevalent in the developing countries. Cereals are generally deficient in essential amino acid lysine but are a good source of sulfur containing amino acids. On the other hand, legumes rich in lysine are poor in sulfur containing amino acids. Thus, the optimal nutritional combination could be achieved by a diet that is composed of roughly 65% cereal and 35% legume. Legumes also have shown numerous health benefits, for example, lower glycemic index for people having diabetes, cancer prevention and protection against cardiovascular diseases due to their dietary fiber content [30, 47]. Indiscriminate and massive use of chemical fertilizers and pesticides – the two inseparable key elements of modern agriculture system (called Green Revolution) are basically responsible for the contamination of 'Soil -Water-Food' matrix. In fact, modern agriculture is proving unsustainable on all fronts viz. energy, environment, health, and socio-economical aspects.

In a tropical country such as India, agriculture is a way of life, not just agribusiness, it demands a holistic perspective in searching a pragmatic sustainable solution. The alternatives must be capable to explain the intrinsic interrelationships of man and nature. In view of the above, several alternative agriculture systems are identified worldwide [10]. However, due to several inherent socio-technical reasons especially in developing countries, diffusion and acceptance of these alternatives may be quite difficult and slow. The long term solution to the problem of 'Food Quality and Safety', demands a drastic change in our thinking and perspective in all spheres of human activities. Agriculture, being the base of all life forms, would play a significant role in the journey towards sustainable development. Since paradigm shift to ensure the "Food Quality-Food Security" nexus takes a long time, therefore, it is important to find a pragmatic solution in the transient phase. The grains contaminated with pesticide residues pose a grave risk to food safety. Pesticide contamination has serious implications for both the environment and human health. So, it is necessary to understand the pattern of pesticide usage, pathway of intake and their environmental impacts.

3 Pesticides –Types, Application, Environmental Impacts and Human Health

Chemical pesticides have contributed to increase the yields of agricultural products by controlling pests and plant's diseases, and to control the insect-borne diseases, such as malaria, dengue, encephalitis, and filariasis [43]. The need to increase world food production for the rapidly growing population is well recognized [6]. One of the strategies to increase crop productivity is effective pest management because around 25–30% of annual food production is lost due to pest infestation [31]. In tropical countries, crop losses are even more severe because the prevailing high temperature and humidity, which allows rapid multiplication of pests [29]. Thus, the application of a wide variety of pesticides on crop plants is relatively unavoidable in the tropics to combat pests [1].

Major pesticides used in crop production include organophosphates (such as malathion, chlorpyrifos), organochlorines (endosulfan, lindane, aldrin, dieldrin), synthetic pyrethroids (deltamethrin, cypermethrin, bifenthrin) and carbamates (carbaryl, bendiocarb) [42], while mainly pyrethroids (deltamethrin, cypermethrin, bioresmethrin) and organophosphates (malathion, chlorpyrifos) are employed during storage [11, 34, 35].

3.1 *Environmental Impact of Pesticides*

The sporadic use of chemical pesticides has led to significant consequences not only for public health but also for environmental consequences due to the development of pesticide resistant pests. The overuse and/or misuse of pesticides not only increases the crop production cost but also contributes to the adverse environmental and health consequences. Inappropriate application of pesticides affects the whole ecosystem by entering the residues in food chain and polluting the soil, air, ground, and surface water [5, 54].

Pesticide pollution to the local environment also affects the lives of birds, wildlife, domestic animals, fish, and livestock. The use of un-prescribed pesticides in inappropriate doses is not only disturbing the soil conditions, but is also destroying the healthy pool of natural bio-control agents, which are normally co-exist with the vegetation. These biocontrol agents are the friends of agriculture and hence need to be nurtured, cared and developed by reducing the reliance on the use of chemicals in agriculture [21].

3.2 *Health Impacts of Pesticides*

Humans are exposed to pesticides (found in environmental media such as soil, water, air and food) by different routes, such as inhalation, ingestion and dermal contact [43]. Exposure to pesticides results in acute and chronic health problems.

Pesticides used in agricultural tracts are released into the environment and come into human contact directly or indirectly [13]. Increasing incidences of cancer, chronic kidney diseases, suppression of the immune system, sterility among males and females, endocrine disorders, neurological and behavioral disorders, especially among children, have been attributed to chronic pesticides' poisoning. Human health hazards vary with the extent of exposure. Moderate human health hazards from the non-judicious application of pesticides include mild headache, flu, skin rashes, blurred vision, and other neurological disorders, while rare, but severe human health hazards include paralysis, blindness and even death [5].

Orgnochlorine insecticides, such as dichlorodiphenyltrichloroethane (DDT), hexachlorocyclohexane (HCH), aldrin and dieldrin, are among the most commonly used pesticides in the developing countries of Asia. In 1998 DDT was banned in India for agricultural use (http://www.chem.unep.ch/pops/POPs_Inc/press_releases/pressrel-2k/pr27.htm). India still is the largest producer and consumer of DDT primarily for vector control however, in 2007 the usage came down to almost one-fourth of 2005 levels but it is still used clandestinely for agricultural purposes [57]. This is due to their low cost and versatility against various pests [22]. Nevertheless, because of their potential for bioaccumulation and biological effects, these compounds were banned in developed nations about two and half decades ago [44]. Their resistance to degradation has resulted in contamination universally found in many environmental compartments. Such residues may be comprised of many substances, which include any specified derivatives, such as degradation products, metabolites and congeners that are considered to be of toxicological significance.

According to the Food and Agriculture Organization (FAO) inventory [17], more than 500,000 tons of unused and obsolete pesticides are threatening the environment and public health in many countries. Public concern over pesticide residues has been increasing during the last decade. Recovering from the euphoria of green revolution, major agricultural producing countries are also now battling from residual effects of extensively used chemical fertilizers especially in ground water and pesticides such as HCH, DDT, endosulfan, phorate in food matrix and water [1, 6, 43]. Hence, on account of their widespread usage in crop protection and their persistence in the environment, the presence of pesticide residues in food cannot be ruled out.

4 Pesticide Residues in Food

As mentioned earlier, pesticides are widely used chemical substances throughout the world in agriculture. Indiscriminate pesticide usage, their high biological activity, and in some cases their persistence may result in pesticide residues in food, feed and dairy products. The widespread contamination of organochlorines may be due to their direct application or more importantly from industrial emission in environment [4]. In India pesticide residues have been reported as early as 1966 at Pantnagar, Uttaranchal [53] when all the samples of edible grains showed the presence of DDT. Since then, there have been numerous reports of widespread pesticide contaminants present in food [5]. Market samples of wheat and pulses in India were analyzed for the presence of pesticides and found to be contaminated with DDT (83 ppm) and BHC (63 ppm) [25]. Similarly, Majumdar [37] reported the contamination of seed samples of wheat, maize, sorghum and bajra with very high levels of DDT, BHC and Captan. It can therefore be concluded that stored grains can be highly contaminated with pesticides as these are stockpiled and periodically treated with pesticides to control pest infestation. In a review on pesticide residues in grains, 91% of the wheat sampled by the FDA contained pesticide residues [23]. Residues have also been reported in wheat products like wheat flour.

Dissipation of pesticides is low during storage of grains contaminated with different pesticides. Grains treated with chemical pesticides show presence of bound residues even after fairly long periods of storage contributing to dietary intake of pesticides [35]. The widespread contamination in pulses is due to the extensive application of pesticides to control pests, as these are highly susceptible to pest attack right from the crop production to the storage level [49]. In view of the above mentioned hazards of chemical pesticides, it is therefore important to evaluate simple, cost effective strategies to enhance food safety from harmful pesticides. Food processing at domestic and industrial level may offer a suitable means to tackle the current scenario of unsafe food.

5 Towards a Sustainable Approach for Food Safety in the Transient Phase

A sustainable and pragmatic solution to tackle above mentioned food safety and quality concerns have been reported in the development and propagation of alternative agriculture systems like organic farming, biodynamic agriculture, permaculture, and pesticide free farming [48]. Therefore, simple and cost effective strategies for addressing these concerns in the transient phase (i.e. complete shift to sustainable agriculture) are urgently warranted.

Provision of adequate nutrients/proteins of animal origin is difficult, expensive and may be unacceptable under certain socio-cultural conditions. So, an alternative for improving nutritional status of the people is to supplement the diet with proteins of plant origin. Food legumes form an important part of the vegetarian diet because of their high nutritive value. However, the presence of several anti-nutritional factors like phytates, lectins, trypsin and chymotrypsin inhibitors can impede the availability of nutrients, and, thereby, limit the consumption of legumes. Processing provides a suitable means to tackle the scenario of poor food quality by improving the nutritive value of legumes by reducing the anti-nutrients, and enhancing the digestibility of protein and starch [41]. Similarly, domestic processing may help in the dissipation of pesticide residues in raw food [3].

6 Food Processing Techniques and Food Safety (Pesticide Residues)

Pesticides (i.e. insecticides and fungicides) are used globally for the protection of food, fiber and human habitats from insect-pest infestation. However, their excessive use and/or misuse (especially in the developing countries), their volatility, long-distance transport eventually results in widespread environmental contamination. In addition, many older, non-patented, more toxic, environmentally persistent and inexpensive chemicals are used extensively in developing nations, creating serious acute health problems as well as local and global environmental impacts [15]. Further, while remarkable progress has been made in the development of effective pesticides, the fact remains that a very small fraction of all applied pesticides is directly involved in the mechanism of pesticide action, which implies that most of the applied pesticides find their way as 'residue' in the environment and subsequently into the terrestrial and aquatic food chains. These chemicals undergo accumulation and exert potential long term adverse health effects [60].

Food processing at domestic and industrial level would offer a suitable means to tackle the current scenario of unsafe food. Food processing techniques imply the set of methods and techniques used to transform raw ingredients into food or to transform food into other forms for consumption by humans or animals either at home or by the food processing industry. Unit operations, normally employed in processing food crops, reduce or remove residues of insecticides and other pesticides. These operations such as washing, peeling, blanching, and cooking play a major role in the reduction of residues [16]. Each operation has a cumulative effect on the reduction of the pesticides present [20].

Washing removes loose surface residues and major portions of polar compounds such as carbaryl. Hot water blanching increases pesticide removal and may hydrolyze substantial fractions of non-persistent compounds [18]. Table 1 summarizes the effect of selected domestic processing techniques on pesticide residue dissipation in grains.

6.1 Effect of Washing on Pesticide Residues

Washing is the most common form of processing which is a preliminary step in both household and commercial preparation. Loosely held residues of several pesticides are removed with reasonable efficiency [52]. Researchers reported that chlorpyrifos and its breakdown product 3, 5, 6-trichloro-2-pyridinol (TCP) were recovered from spiked rice grains in the levels of 456 and 3.4 ppb, respectively. Washing rice grains with water removed approximately 60% of the chlorpyrifos residues [36].

Table 1 Effect of different food processing techniques on pesticide residue dissipation in grains

S.No.	Processing	Commodity	Pesticide	Initial residues (ppm)	Final residues (ppm)	% residue dissipation	Reason	Reference
1.	Bread Making	Wheat flour	Endosulfan Deltamethrin Malathion Propiaconazole Chlorpyriphos Hexaconazole	4.0	1.20 1.48 1.60 1.92 1.96 2.16	70 63 60 52 51 46	Bread making process involves yeast-mediated fermentation and baking which contribute to degradation of pesticides	[50]
2.	Milling and storage for 365 days	Wheat	Phoxim-methyl	10.0	9.0	8–10	During milling, residues accumulate in the bran fractions and reduced in white flour	[8]
3.	Milling	Whole grain	Deltamethrin.	1.84	1.06	42.39		[38]
4.	Milling	Wheat	Malathion	8.89	0.45	95		[55]
5.	Parboiling	IR 20 paddy	Ekalux 25 EC 0.05% Dursban 25 EC 0.05% Lebaycid 100 EC 0.05%	0.08–0.09	0.02–0.04	49 51 68	Reduction due to parboiling may be due to inactivation or degradation of the pesticides during parboiling at high temperature (100 °C).	[33]
6.	Parboiling	Rough rice	Malathion	14	0.01	99%		[14]

(continued)

Table 1 (continued)

S.No.	Processing	Commodity	Pesticide	Initial residues (ppm)	Final residues (ppm)	% residue dissipation	Reason	Reference
7.	Storage for 6 months at 26.7 °C	Wheat Maize Sorghum	Malathion	10	8.5	85% of total residue remained on outside of grain after 24 h, residues increased inside the grain and decreased markedly on the outside during the first month, and residues disappeared more rapidly from the outside than from the inside during the remaining storage time		[27]
8.	12 months of storage in an open basket	Maize grains Beans	Malathion	7.73 7.52	2.78 3.99	64 47	These high losses were explained by volatilization and possible settling of pesticide dust formulation to the bottom and on the sides of basket during storage in the open and windy tropical laboratory [35]	[35]

9.	Milling and storage for 4–36 weeks respectively	Wheat grain	Chlorpyrifos-methyl Etrimfos Fenitrothion Malathion Methacrifos Pirimiphos-methyl	3.7 5.0 6.8 8.2 2.6 3.4	3.6 4.6 3.0 4.1 1.3 2.3	2.7 0.08 63.33 50 50 32.35		[59]
10.	Storage around 6 months	Barley	Malathion	10.2	3.0	65–72%		[56]
11.	Cooking without and with NaCl	Maize gains Beans	Malathion	2.79 4.10		56.7% and 69.7% 64.2 and 75%		[35]
12.	Washing (twice)	Soybeans	Dichlorvos Malathion Chlorpyriphos Captan	5.01 7.9 11.2 2.87		80–90%	sprayed pesticides remain as microparticles on the surface of the soybeans and are easily removed by mechanical stirring in water [39]	[39]

From an initial level of 19 ppm in rice almost all the permethrin in rice was removed by washing with water [19]. Washing of soybeans twice with water reduced the pesticides by 80to 90% of dichlorvos (initial concentration 5.01 ppm), malathion (initial concentration 7.9 ppm), chlorpyriphos (initial concentration 11.2 ppm), and captan (initial concentration 2.87 ppm). These results suggest that sprayed pesticides remain as microparticles on the surface of the soybeans and are easily removed by mechanical stirring in water [39].

6.2 Effect of Cooking Process on Pesticide Residues

Cooking is a step of preparing food easy for eating and digestion. It encompasses a vast range of methods depending on the customs and traditions, availability, and the affordability of the resources. Literature is replete with work on effect of cooking on pesticide residues dissipation in fruits and vegetables, while it is relatively less studied in grains. Watanabe and co-researchers demonstrated that holding mustard samples containing fenvalerate (0.081–1.3 ppm) and dimethoate (0.020–0.070 ppm) in boiling water for 10 min reduced the dimethoate levels by half but only slightly lowered fenvalerate levels [58]. Researchers also demonstrated that the total residues removed from maize grains by cooking (without and with NaCl, respectively) alone were 56.7% and 69.7%, and that for beans were 64.2% and 75%. It is important to note that though malathion and its polar metabolites, a- and b-monoacids of malathion were completely eliminated by boiling; malaoxon was still detected in quite high quantities in the solvent extracts of cooked beans and maize [35].

The disappearance of pesticide residues from boiling extract could be due to decomposition by the effect of heat, the stronger adsorption of pesticide onto plant tissues and/or the poor solubility of pesticides in water [2, 7]. Hence, heat can increase volatilization, hydrolysis or other chemical degradation and thus reduce residue levels [24]. It was observed that after 6 months of pesticide treatment, 22–23% deltamethrin residues were present in the grains. Culinary applications like washing and steaming dislodged the residues by 40–60% from stored chickpea grains. Steeping of grains in water and deskinning thereafter could reduce the residues maximum to extent of 37% but was still not able to bring it to safe levels [34]. Similarly, it was found that decontamination processes like washing and cooking rendered chickpea pods safer for consumption from fenpropathrin residues [32].

Parboiling means precooking of rice within the husk. It involves first hydrating paddy followed by heating to cook the rice followed by drying. Rough rice was treated with malathion (concentration 14 ppm) or chlorpyriphos methyl (Reldan) (concentration 6 ppm). The residue concentrations of malathion in non-parboiled rice and parboiled rice are 0.016 ppm and 0.013 ppm, respectively; on the other hand, the average residue concentrations of Reldan in non-parboiled rice and parboiled rice are 0.05 ppm and 0.065 ppm, respectively [14].

6.3 Other Processing Techniques Causing Pesticide Residue Dissipation

Different processes, like bread making, milling, washing and infusion, have also been found to cause considerable pesticide residue dissipation. Commercially produced bread is an important component of every day diet in many countries. During bread making process, bread was prepared from wheat flour spiked at different concentrations (1, 2, 3 and 4 ppm) with endosulfan, hexaconazole, propiaconazole, malathion, chlorpyriphos and deltamethrin. It was observed that at 4 ppm level of spiking the degradation of endosulfan, deltamethrin , malathion , propiaconazole, chlorpyriphos and hexaconazole were 70%, 63%, 60%, 52%, 51%, and 46%, respectively. Yeast-mediated fermentation and baking at high temperature lead to the degradation of the pesticides [50].

The milling of grains substantially removes the residues. Most residues are present in the outer portions of the grain and consequent levels in bran are consistently higher than in wheat, usually by a factor of about 2–6. Even for the pesticides which can enter the grain by translocation, residues are higher in the bran than in the flour [24]. In laboratory tests, pirimiphos-methyl was applied to wheat at toxicant concentrations of 7.3 and 14.6 ppm. The residues in milling fractions even after 12 months (treatment at 7.3 ppm) accounted for 81.8% of the residues found on the whole grain, and at 14.6 ppm accounted for 79.01% of the residues present on the grains [28]. However, recent findings project a different picture about the effectiveness of the milling process with about 95% reduction of malathion residues reported in wheat through milling [55].

7 Grain Storage and Pesticide Residue Dissipation

Grains are generally stored for long duration (3–36 months) at ambient temperatures in bulk silos, where a number of insecticides may be applied to reduce losses during storage [24]. Grain based foods, therefore, have the potential to be a major source of residues of these insecticides in the diet. Studies on post-harvest treatment of grain with insecticides have generally shown that residues only decline rather slowly [24, 51]. Residues of the more lipophilic materials tend to remain on the seed coat although a proportion can migrate through to the bran and germ which contain high levels of triglyceride [9, 24].

Residues generally showed little decrease over 32 weeks at 20 °C and 50–70% relative humidity. At 30 °C malathion residues decreased by 30–40% while pirimiphos-methyl residues remained constant. Organochlorine and synthetic pyrethroid residues are also very stable under silo conditions [24, 45]. Persistence of several insecticides in grains and beans stored under typical conditions has been studied in a number of countries using radiotracer techniques [24, 26]. Extractable residues of parent maldison after storage periods of 3–9 months ranged from 16%

to 65% of the applied doses. Considerable amounts of hydrolysis products were also present and bound residues (radioactivity un-extractable by the solvent used) comprised 52% of the applied dose.

Chlorpyrifos-methyl, fenvalerate and pirimiphos methyl were generally more persistent than malathion [24]. The rate of degradation and penetration of malathion applied at a concentration of 10 ppm on wheat, maize and sorghum grain during storage for six months at 26.7 °C was determined. The results, which were similar to all three types of grain, showed that 85% or more of the total residue remained on the outside of the grain after 24 h. Residues increased inside the grain and decreased markedly on the outside during the first month, and residues disappeared more rapidly from the outside than from the inside during the remaining storage time [27]. Wheat grain treated with chlorpyrifos-methyl, etrimfos, fenitrothion, malathion, methacrifos, pirimiphos-methyl at 3.7, 5.0, 6.8, 8.2, 2.6 and 3.4 ppm, respectively, and stored for 4–36 weeks had residue levels in the flour of 3.6, 4.6, 3.0, 4.1, 1.3 and 2.3 ppm, respectively [59]. After 12 months storage of malathion dosed maize grains (initial malathion concentration 7.73 ppm) and beans (initial malathion concentration 7.52 ppm) in an open basket, the concentration of malathion reduced to 64% and 47%, respectively. These high losses of malathion were explained by volatilization and possible settling of the pesticide dust formulation to the bottom and on the sides of basket during storage in the open and windy tropical laboratory [35]. The effect of storage on the breakdown of malathion (initial concentration 10.2 ppm) was examined during five and a half months of storage. While the degradation of malathion and isomalathion was 65–72%, the malaoxon was degraded extensively (85%) during the storage period [56].

8 Conclusion

Widespread contamination of food commodities with harmful chemical compounds has reaffirmed the significance of safe and high quality food products. Food contamination can occur inadvertently due to direct or indirect exposure to toxic chemicals. Hence, a sustainable solution to this scenario of unsafe and poor quality food warrants a paradigm shift in the current mindset. In view of the above, several alternative agriculture systems such as organic farming, permaculture, and biodynamic farming have been developed in different parts of the world. However, due to several inherent socio-technical reasons especially in developing countries, diffusion and acceptance of these alternatives may be difficult and slow. Domestic processing may help in the dissipation of pesticide residues in raw food during this transient phase. Unit operations, normally employed in processing food crops to reduce or remove pesticide residues and insecticides. These operations such as washing, peeling, blanching and cooking play a role in the reduction of residues. Each operation has a cumulative effect on the reduction of the pesticides present. Therefore, a combination of processing techniques would render food grains safe for human consumption.

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Analytical Methods in Measuring Pesticides in Foods

M.D.H. Prodhan, S.N. Alam, and M. Jalal Uddin

1 Introduction

Production of food produces are seriously affected by insect pests and diseases. Due to plant pests and diseases, 20–40% of the crop yields are reduced globally [1]. To overcome these situations farmers are using different kind of pesticides. Pesticides play a key role to control the insect pests and diseases and hence protect and promote production [2]. However, pesticides and pesticide residues in foods may cause several adverse effects on human health and the environment [3–5].

Nowadays food safety is a major concern to the consumers [6]. The percentage of food containing pesticide residues has increased in the last 10 years. In order to ensure the supply of safe food, pesticides should be used following Good Agricultural Practices (GAP). Monitoring of pesticide residues in the food is the essential tool to ensure GAP. To monitor pesticide residues in the commercial produces, reliable multi-residue analytical methods are required. Multi-residue analytical methods, which allow the quantification of residues of different analytes simultaneously in a single run, are used advantageously for monitoring purposes. This chapter will briefly discuss different extraction, and analytical detection techniques of pesticides residues in foods.

2 Pesticide Residue Analysis

Concern about pesticide residue analysis is increasing day by day due to the consumers demand for safe food and to serve the trade related obligations [7]. Methods to analyze pesticide residues involve two steps: (a) extraction and clean-up of the target analytes from the matrix, and (b) determination of the target analytes.

M.D.H. Prodhan • S.N. Alam (✉) • M. Jalal Uddin
Bangladesh Agricultural Research Institute, Gazipur 1701, Bangladesh
e-mail: alamsn09@gmail.com

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2.1 Extraction and Clean-Up

The sample preparation methods to detect pesticide residue in food matrices involve: extraction of target analytes from the bulk of the matrices and partitioning of the residues in an immiscible solvent, and/or clean-up of the analytes from the matrix co-.extractives. Complex samples like meat and meat products require two step clean-up which combines different chromatographic techniques [8].

Different techniques are used to extract and clean-up of pesticides from different food matrices, such as: liquid-liquid extraction (LLE), super critical fluid extraction (SFE), microwave-assisted extraction (MAE), solid phase extraction (SPE), solid phase micro extraction (SPME), stir-bar sorptive extraction (SBSE), and QuEChERS extraction etc.

2.1.1 Liquid–Liquid Extraction (LLE)

Liquid–liquid extraction is an important separation technique, which is also known as solvent extraction and partitioning. It is widely used in the modern process industry and it is a basic technique in the chemical laboratories. This extraction technique is mainly based on different degrees of solubility of components in two immiscible, or partially miscible, liquids. It is a separation technique of a substance from one liquid into another liquid phase. Both of the liquids are thoroughly contacted and subsequently separated from each other again.

2.1.2 Supercritical Fluid Extraction (SFE)

Supercritical fluid extraction is a technique where supercritical fluids are used as the extracting solvent to separate one component or to separate desired analytes (pesticides) from the matrix. Usually CO_2 is used as a supercritical fluid. This technique is more effective for the solid matrix but it can also be used to separate desired analyte from the liquid matrix. This extraction process is used for analytical purposes to extract the analytes from the matrix, and to strip unwanted material from a product (decaffeination) or collect a desired product (e.g. essential oils).

2.1.3 Solid-Phase Extraction (SPE)

Solid phase extraction (SPE) is a rapid, reliable, and selective sample preparation technique. Solid phase extraction technique is used to extract the analytes from different matrices such as urine, blood, water, beverages, soil, and animal tissue [9]. In the analytical laboratories, this extraction technique is used to concentrate and purify samples for analysis using HPLC, GC, GC-MS and LC-MS/MS. It extends the lifetime of chromatographic systems and improves the qualitative and quantitative analysis.

2.1.4 Solid-phase microextraction (SPME)

Solid-phase microextraction is a fast, solvent-free extraction technique that involves the use of a fiber coated with an extracting phase, which can be a liquid or a solid [10]. Different kinds of analytes including volatile and non-volatile compounds from different kinds of media are extracted by this extraction technique [11]. SPME is compatible with analyte separation/detection by GC or HPLC, and provides a very good result for wide concentrations of analytes.

2.1.5 Stir Bar Sorptive Extraction (SBSE)

Stir-bar sorptive extraction (SBSE) belongs to a group of techniques which was first developed for sampling in liquid phase and is based upon sorption of the investigated analytes or fraction onto a very thick film of PDMS coated onto a glass-coated magnetic stir bar (commercially known as Twister, Gerstel GmbH, Muelheim, Germany).

2.1.6 Microwave-Assisted Extraction (MAE)

Microwave-assisted extraction is an efficient method that involves deriving natural compounds from raw plants. MAE technique allows organic compounds to be extracted more rapidly, with similar or better yield as compared to conventional extraction methods.

2.1.7 QuEChERS Extraction

One of the latest extraction and clean-up techniques for pesticide residue analysis in food matrices is the QuEChERS (quick, easy, cheap, effective, rugged and safe) technique, which was first introduced by Anastassiades et al. [12] in 2003. QuEChERS employs a novel and much quicker dispersive solid phase extraction (dSPE) cleanup. This technique was modified by several research groups (AOAC Official methods, 2007.1; the European Committee for Standardization (CSN) Standard Method, CSN EN 15662, 2008) [13, 14]. Because of high analyte recoveries, the low organic solvent consumption, and the low cost per sample, QuEChERS technique is gradually gaining popularity compared to other existing technique.

At present QuEChERS technique is widely used for the extraction and clean-up of the extracts of **fruit and vegetable matrices** [1, 15–40], **dairy and fatty matrices** [41–44], matrices of **grains, nuts and seeds** [38, 45–49], and matrices of **baby foods** [50–60].

2.2 Pesticide Residue Determination

Gas Chromatography (GC), Gas Chromatography associated with Mass Spectrometry (GCMS), High Performance Liquid Chromatography (HPLC), and Liquid Chromatography associated with Mass Spectrometry (LC-MS) are the most commonly used techniques to detect pesticides and pesticide residues in foods.

2.2.1 Gas Chromatography (GC)

A gas chromatograph (GC) is an analytical instrument that measures the content of various components in a sample. There are different detectors, with different types of selectivity, can be used in gas chromatography. Flame ionization detector (FID) is feasible for most of the organic compounds. Thermal conductivity detector (TCD) is a universal detector. Electron capture detector (ECD) is used for halides, nitrates, nitriles, peroxides, anhydrides, organometallics etc. Nitrogen-phosphorus detector (NPD) is normally used for nitrogen, phosphorus and the Flame photometric detector (FPD) is used for sulphur, phosphorus, tin, boron, arsenic, germanium, selenium and chromium. Till date, GC technique with different detectors are used for the quantification of pesticide residues from different food matrices [81, 87–94].

2.2.2 Gas Chromatography–Mass Spectrometry (GC–MS)

In GC-MS, pesticides are identified by retention time and specific ions, and quantified by selected ion monitoring (SIM) mode using the target and qualified ions. SIM mode provides adequate quantification at low concentration. However, the accuracy may be reduced if the selected ions are affected by matrix effect. Besides using the MS/MS it is possible to decrease the matrix effects, may achieve a higher selectivity levels and lower detection limit [51, 76]. GC-MS/MS with triple quadrupole [76, 77] and ion trap mass spectrometers [77] has been used for pesticide residue analysis on fatty food. To analyze multiple pesticide residues from food matrices using GC-MS, acquisition mode, multiple reaction monitoring (MRM) [76], and the selected reaction monitoring (SRM) [78] mode have been used. Several single and multiresidue methods using GC-MS have been developed for the analysis of pesticides from different classes [79–88].

2.2.3 Liquid Chromatography-Mass Spectrometry (LC-MS)

In recent years, LC-MS has been used to determine pesticide residues in fruit and vegetable extract. LC-MS is an effective technique that generally reduces the excessive clean-up steps, exhibits little chance of false-positive findings, and reduces the analysis time and cost [61]. The high sensitivity of LC-MS technique makes it useful in many applications. Different mass analyzers are used in

LC-MS, including single quadrupole, triple quadrupole, ion trap, and time of flight mass spectrometry (TOF-MS). LC-MS/MS with electrospray ionization (ESI) and atmospheric pressure chemical ionization (APCI) source are used widely to analyze multiple pesticide residues from a wide variety of matrices [2, 21, 62–73]. A wide range of pesticides can be analysed by both GC-MS and LC-MS techniques. However, LC-MS is considered to cover a wider scope than GC-MS [74]. LC-MS/MS with ESI (electrospray ionization) and APCI (atmospheric pressure chemical ionization) source have improved the feasibility of the identification of pesticides of different chemical structures in food at concentrations comparable to those obtained by GC-MS [75].

2.2.4 High Performance Liquid Chromatography (HPLC)

High Performance Liquid Chromatography (HPLC) has been used for manufacturing (e.g. during the production process of pharmaceutical and biological products), legal (e.g. detecting performance enhancement drugs in urine), research (e.g. separating the components of a complex biological sample, or of similar synthetic chemicals from each other), and medical (e.g. detecting vitamin D levels in blood serum) purposes. Nowadays, HPLC is mostly used for the purity analysis of pesticides. It is also used for single pesticide residue analysis of different food matrices [15, 89].

The commonly used detectors for pesticide residue analysis are UV-VIS Detector, Photo Diode Array Detector (PDA) and Fluorescence Detector. UV-VIS Detector is the most commonly used detector. The response of UV-VIS Detector is specific to a particular compound or class of compounds depending on the presence of light absorbing functional groups of eluting molecules. Fluorescence detector gives higher sensitivity than a UV-VIS detector. Photo Diode Array Detector (PDA) helps to monitor simultaneous determination of more than one absorbing component at different wavelengths.

3 Conclusion

Analytical methods discussed in this chapter play an important role for the qualitative and quantitative detection of pesticide residues in food matrices. Prior to analyze the sample, the analytical methods should be validated in terms of accuracy, precision, limit of detection (LOD), limit of quantification (LOQ), and linearity [95].

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Alternatives of Pesticides

Laila Hossain, Rizwanur Rahman, and Mohidus Samad Khan

1 Introduction

Pesticides are widely used in agriculture to control insects, microorganisms, fungi, weeds and other pests. The control of these pests serves to increase crop yield and to decrease manual labor [1]. However, majority of chemical pesticides pose long term danger to the environment and humans through their persistence in nature or in body tissues. Because of the health and environmental hazards, worldwide pest management is facing economic and ecological challenges [2]. To overcome these challenges, regulatory actions have been taken by regulatory and environmental protection agencies of different nations, and synthetic chemical pesticides are being replaced by 'organic' chemicals, such as: biopesticides, which pose lower or no risk to the environment and human health. However, lack of efficacy, inconsistent field performance and high production cost have been relegated them to niche products. Often, the cost of fermentation of microbes is higher than the cost of making a synthetic chemical. It is also required huge funds for research and to develop new products, or to improve existing products.

Biopesticides are often specific to different species of pests; hence, farmers may need to have different biopesticide products to control multiple species of pests. Bioactive products also tend to have shorter shelf lives and are degraded rapidly in sunlight [3]. To use biopesticides effectively, growers need to know a great deal about the lifecycle of the pests or pathogens they are trying to control. Farmers also need to understand the timing and appropriate conditions for application of the biopesticide products. Therefore, it is important to provide sufficient training and protocols to help growers to adopt the broad-spectrum agrochemicals.

In addition to biopesticides options, different cultural societies have adapted and implemented different alternative techniques, such as: cultural tactics, physical,

L. Hossain • R. Rahman • M.S. Khan (✉)
Department of Chemical Engineering, Bangladesh University of Engineering and Technology (BUET), Dhaka 1000, Bangladesh
e-mail: mohid@che.buet.ac.bd

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mechanical and biological tactics, behavioral control tactic using semiochemicals and transgenic crops to address and minimize issues pertaining to pesticides [4]. Cultural control involves regular farm operations and does not require the use of specialized equipment or additional skills. Often, they are considered as the best methods to reduce pests since they combine effectiveness with minimal additional labor and cost [5]. Maintaining optimal growth conditions, altering sowing season and sowing method, reaping secondary host plants, intercropping, crop rotation, and crop sanitation are some common techniques of cultural control method [4, 5]. Preventive, corrective physical and mechanical methods differ from cultural methods since they are intended specifically to control pests and their effectiveness is regarded with temperature, heat, radiation and untrasonic vibrations [6]. Through the actions of living organisms, such as: predators, parasites and pathogens, the reproductive potential of a specific pest organism can be suppressed [4, 6]. Botanical pesticides are extracted from plants and are used as alternatives of synthetic pesticides showing lesser toxicity to humans [2]. To control the pests in most effective way, nowadays, multiple pest control methods are adapted contemporarily. This combined pest controlling method is known as Integrated Pest Management (IPM). IPM involves the selection, integration, and implementation of pest control based on predicted economic, ecological and sociological consequences including weather, disease organisms, predators and parasites [7].

In this chapter, different alternatives of pesticides and pest management techniques are discussed. The basic features of alternative plant protection tactics and their integration are also outlined. The market statistics of biopesticides and their universal consumption information are also illustrated.

2 Global Pesticide Consumption and Pollution

Since the 1990s, the global pesticide sale remained relatively constant, between 270 and 300 billion dollars, of which 47% were herbicides, 79% were insecticides, 19% were fungicides/bactericides, and 5% the others [8]. Over the period of 2007–2008, herbicides were ranked first among three major categories of pesticides (insecticides, fungicides/bactericides, herbicides). Use of fungicides/bactericides was increased rapidly and ranked second [8]. Europe is now the largest pesticide consumer in the world, and Asia is ranked second under this category. As for the countries, China, the United States, France, Brazil and Japan are the largest pesticide producers, consumers or traders in the world [8].

2.1 World Pesticide Trade

Table 1 represents the recent data of pesticide import and export of different major countries [9]. From Table 1 it can be seen that import and export of France, Germany and China are significantly high. Pesticides exported from the United States,

Table 1 Import/export of pesticides of some major countries in recent years [9]

Country	Category	Import (US$Million)				Export (US$Million)			
		2003	2004	2005	2006	2003	2004	2005	2006
USA	Insecticides	96.95	124.74	128.63	117.25	431.47	501.80	373.46	468.55
	Fungicides	179.53	236.76	244.23	152.30	220.98	274.67	258.39	286.20
	Herbicides	310.73	304.71	282.87	298.06	13.68	16.02	22.31	21.86
	Disinfectants	43.25	46.54	45.03	55.70	157.94	167.47	152.18	168.29
Germany	Insecticides	91.35	91.88	100.06	85.38	270.77	286.10	289.01	339.15
	Fungicides	240.26	243.19	335.76	309.14	595.34	738.60	737.90	745.52
	Herbicides	275.64	359.26	417.92	436.31	614.29	434.82	507.69	833.75
	Disinfectants	105.52	145.99	146.56	144.54	325.17	363.04	373.49	436.89
France	Insecticides	268.21	294.94	288.45	262.50	397.70	536.94	492.16	416.59
	Fungicides	571.39	590.38	712.55	459.20	554.13	767.75	885.30	779.65
	Herbicides	482.94	682.20	657.92	595.42	827.63	1225.87	1069.50	1144.22
	Disinfectants	104.25	111.02	115.22	145.20	79.04	103.27	119.89	137.15
China	Insecticides	102.44	104.37	116.97	123.47	294.26	481.71	533.54	377.60
	Fungicides	90.09	99.84	104.42	117.96	149.86	228.14	275.27	147.99
	Herbicides	77.48	78.71	104.15	120.98	361.74	553.63	668.26	597.05
	Disinfectants	32.55	27.07	36.27	38.30	14.63	13.68	14.38	13.55
Japan	Insecticides	54.98	59.25	86.15	95.66	107.27	116.78	118.85	136.72
	Fungicides	95.37	99.19	90.83	91.85	74.21	78.39	78.06	72.61
	Herbicides	82.30	98.12	109.46	117.62	74.29	86.32	96.91	91.91
	Disinfectants	10.39	9.64	9.64	9.46	13.27	16.24	15.53	13.69
Thailand	Insecticides	57.79	61.98	70.77	100.54	23.23	17.59	18.33	28.56
	Fungicides	39.24	40.43	38.99	48.20	3.19	2.32	2.74	7.61
	Herbicides	126.17	132.59	128.11	169.73	7.53	3.25	2.56	7.00
	Disinfectants	18.98	22.89	25.03	25.86	13.17	14.16	17.74	23.16

(continued)

Table 1 (continued)

Country	Category	Import (US$Million)				Export (US$Million)			
		2003	2004	2005	2006	2003	2004	2005	2006
Vietnam	Insecticides	62.96	76.70	87.33	123.19	6.32	9.51	10.51	17.49
	Fungicides	53.10	66.06	81.01	96.24	0.76	0.22	0.49	1.30
	Herbicides	47.39	64.98	65.87	70.71	2.53	4.64	8.00	8.67
	Disinfectants	23.71	19.77	20.29	29.08	0.42	0.65	0.43	1.15
Australia	Insecticides	29.91	54.47	66.40	66.46	33.29	23.36	25.67	18.74
	Fungicides	39.75	41.73	54.38	53.76	7.04	9.65	10.88	13.80
	Herbicides	92.65	129.82	132.37	133.88	22.91	32.35	29.36	25.25
	Disinfectants	34.09	39.10	30.89	30.17	9.26	8.51	6.25	8.53
South Africa	Insecticides	51.72	68.80	65.32	67.86	35.53	36.58	42.08	48.43
	Fungicides	24.83	31.24	31.82	37.95	13.68	16.02	22.31	21.86
	Herbicides	43.25	46.54	45.03	55.70	77.31	94.81	70.73	51.13
	Disinfectants	6.52	7.08	8.23	8.82	7.10	6.13	8.02	10.18

Germany, France and China was greatly higher than its import from 2003 to 2006. In 2006 the import (export) of herbicides of the United States made up 45.4% (51.6%) of its total import (export) [8]. Germany is the largest producer of pesticide in Europe. France is the largest pesticide consumer in Europe followed by Germany. Other major pesticides consumer in Europe includes Italy, Spain and UK. In 2008, France announced it would voluntarily cut pesticide use by 50% by 2018, and emerged as the European leader in reducing pesticide dependency [10]. According to data from Ministry of Agriculture of China, from 1991 to 2005, consumption of pesticides has been increased around 50% [8]. To increase food production and to reduce agricultural workload, the use of pesticides has rapidly increased in Japan since the end of World War II. Japan's pesticide export to China and Southeast Asian countries is continuously increasing [8]. From the table it can be seen that pesticide import of Thailand and Vietnam was greatly higher than its export from 2003 to 2006. Australia's pesticide import is greatly larger than pesticide export. Of the pesticides imported, the products from China are quickly increasing, including glyphosate, paraquat and glufosinate-ammonium. About 10% of glyphosate are from China [8]. Endosulfan from China is the major cotton insecticide and acaricide in Australia [8]. Pesticide consumption of Africa accounts for about 3% of the world, of which South Africa makes up 2% of pesticide consumption of the world [8]. As the development of Africa's agriculture, pesticide production of South Africa is expected to grow rapidly in the future. South Africa's pesticide import is larger than export. Herbicides accounted for 40% of the total import in 2006.

2.2 *Pesticide Hazard: Global Aspect*

Pesticides are associated with adverse impacts on human health and the environment that have arisen as a result of inappropriate use and handling of pesticides by inadequately trained farmworkers. Agricultural workers are reported to be in a greater risk of acute pesticide poisoning in comparison to non-agricultural workers. Farmworkers can become exposed to pesticides through different routes, such as inhalation, ingestion and skin contact. Exposure to pesticides can result in acute and chronic health problems, which include eye irritation, immune system disturbances, chromosomal damage, respiratory distress, hormone disruption, male genital abnormalities, diminished intelligence and cancer [11, 12]. Pesticides also contaminate waterways, impact non-target and beneficial organisms, and persist in the environment for years. These chemicals have also been shown to reduce ecosystem biodiversity. It is reported that the major contributor to the decline in farmland and grassland birds is due to pesticide use. In 2012, a study showed that widely used herbicides adversely impact non-target invertebrate organisms including endangered species [13]. Overall, the pesticide consumption in Europe has declined over the past decades [8].

About 75% of pesticide usage in the United States occurs in agriculture [1]. Poisoning due to pesticides is a notifiable condition in South Africa [14]. In Australia, increased exposure to glyphosate may give rise to numerous chronic diseases. In China, 53,300 to 123,000 people are poisoned by pesticides each year. Deaths from improper use of pesticides in crop production is about 300–500 per year [15]. A survey indicated that many farmers suffer liver, kidney, nerve and blood problems, eye problems, headaches, skin effects and respiratory irritations due to pesticide poisoning [15].

3 Alternative Tactics of Pest Management

3.1 Cultural Control

Cultural control is the deliberate alteration of the production system by targeting the pest itself through agronomic practices to avoid or reduce pest injuries to crops. These methods are utilized most frequently to control pest related issues. Crop rotation, intercropping, sanitation, trap crops and pest resistant crop plants are few examples of cultural control. These individual tactics of cultural control tend to be pest and crop specific [16].

3.1.1 Tactics to Prevent, Reduce or Delay Pest Colonization of the Crop

Site selection Site selection involves locating the crop field in such a manner that pests, from the site of the previous year's crop or from natural overwintering sites, cannot easily find their way there [4]. The selected sites may also have abiotic and biotic characteristics, which affect pests adversely (e.g. suppressive soils). Pest-free plant material, equipment, and soil play a crucial role to prevent infestation with pests.

Intercropping Intercropping is a practice that involves growing two or more crops in proximity. The most common goal of intercropping is to produce a greater yield on a given piece of land by making use of resources that would otherwise not be utilized by a single crop. Intercropping may concentrate the pest in a smaller, more manageable area so that it can be controlled by appropriate tactic. Strips of *alfalfa*, for example, are sometimes inter-planted with cotton as a trap crop for Lygus bugs (Miridae). The alfalfa, which attracts Lygus bug more strongly than cotton, is usually treated with an insecticide to kill the bugs before they move into adjacent cotton fields. Intercropping of compatible plants also encourages biodiversity, by providing a habitat for a variety of insects and soil organisms that would, otherwise, not be present in a single-crop environment. This in turn can help limit outbreaks of crop pests by increasing predator biodiversity [17]. Additionally, reducing the homogeneity of the crop increases the barriers against biological dispersal of pest organisms through the crop.

Based on spatial arrangement, intercropping can be divided into the following four categories [18]:

(i) Row intercropping: Growing two or more crops at the same time with at least one crop planted in rows.
(ii) Strip intercropping: In this method two or more crops grow together in strips wide enough to allow separate production of crops using mechanical implements but close enough for the crops to interact [19].
(iii) Mixed intercropping: Growing two or more crops at the same time with no distinct row arrangement [19].
(iv) Relay intercropping: Growing of two or more crops simultaneously during part of the life cycle of each crop. In this method, a second crop is planted after the first crop has reached its reproductive stage of growth, but before it is ready for harvest [18].

Based on growth pattern and compatibility, inter-cropping may also be divided into the following groups [20, 21].

(i) Parallel cropping: Under this cropping two crops are selected which have different growth habits and have no competition between each other. This technique allows the crops to exhibit their full yield potential.
(ii) Companion cropping: In companion cropping the yield of one crop is not affected by the other, In other words, the yield of both crops is equal to their pure crops. This technique reduces the risk of total crop failure.
(iii) Multistoried cropping: Growing plants of different heights in the same field at the same time is termed as multistoried cropping. It is mostly practiced in orchards and plantation crops for maximum use of solar energy even under high planting density.

Trap Crops Trap crops are grown as a control measure to lure pests away from the cash crop. Pests are either prevented from reaching the crop or concentrated in certain parts of the field away from the main crop. The principle of trap cropping relies on pest preference for certain plant species, cultivars or a certain stage of crop development [22]. A trap crop can be an early or a late crop of the same cultivar as the main crop, or a different plant species. Pests concentrated in the trap crop should be destroyed with pesticides, natural enemies or cultural methods to prevent them from migrating to the main crop at a later stage [23, 24].

Altering the Time of Planting Plantation and harvest dates of some crops can be rearranged to reduce or to avoid potential pest damage [24]. Early planting ensures that seedlings have reached a non-susceptible or tolerant stage when the pest appears. Planting needs to be done only after the emergence or immigration of the pests leaves the pests without hosts. Early harvest date may prevent pests from reaching damaging population densities or overwintering stage by harvest [16].

3.1.2 Tactics to Reduce Survival of Pests By Creating Adverse Biotic and Abiotic Conditions

Sanitation Sanitation or source reduction involves eliminating food, water, shelter, or other necessities that are important for pest survival [25]. In crop production, sanitation includes practices to remove weeds that harbor pest insects or rodents, to eliminate weed plants before they produce seed, to destroy diseased plant material or crop residues, and to keep field borders or surrounding areas free of pests and pest breeding sites. Animal manure management is an effective sanitation practice used to prevent or to reduce fly related issues in poultry and livestock operation.

Crop rotation Crop rotation interrupts the normal life cycle of pests by placing them in a non-host habitat. It is highly effective to prevent different weeds, soil-borne plant pathogens and root-living arthropods. To control arthropods, rotation is generally most successful against species with long generation cycles and with limited dispersal capabilities. The limiting factor of this tactic is organization of the required land area to perform area-wise crop rotation [26].

Plant and row spacing Sufficiently sparse plant and row spacing are important in preventing plant pathogens that usually require a certain moisture threshold to germinate and grow. In contrast, by increasing plant density it is possible to 'dilute' the damage caused by pests to individual plants.

Tillage and destruction of breeding or overwintering refugia Tillage (soil-turning and residue-burying practices) and seed bed preparation reduce the number of soil-living pest stages [27]. Some forms of tillage can reduce pest populations indirectly by destroying weeds and volunteer crop plants in and around crop-production habitats. Many pests can breed on alternate host plants and migrate from there to crop plants. The removal of the alternative host thus helps in alleviating pest problems.

3.1.3 Tactic to Reduce Injury Caused By Pests to Crop Plants

Plants, resistant to pest attack, are less preferred by pests as they adversely affect the pests' normal development and survival or the plant may tolerate the damage without an economic loss in yield and/or quality [28]. Constitutive plant resistance is easy to use, cheap and compatible with other pest management tactics. Induced resistance to herbivores and pathogens reduces plant exposure to autotoxic environment of secondary compounds [29].

3.2 Physical and Mechanical Control

Physical and mechanical controls either kill insects and small rodents, or make the environment unsuitable for them by attacking, or setting up barriers. These methods are used for crop growing and household pest management.

3.2.1 Barriers

Row covers, typically used for horticulture crops, are useful to keep insects away from plants. These are knitted tenuously with plastic or polyester fiber so that plants can still absorb sunshine and moisture from the air. Diatomaceous earth, made from fossilized and pulverized silica shells, is used to impair the protective cuticle layer of insects, such as: ants. As a consequence, the insects become vulnerable to becoming dry. As moisture diminishes the effectiveness of diatomaceous earth, it must be attributed at regular intervals.

3.2.2 Traps

Devices like fly paper or sticky boards, covered with sticky and poisonous substance, are used to attract insects. Insects, attracted by those traps, land upon the surface and get glued. These traps are commonly used for capturing flies or leafhoppers [30]. Sometimes, a special type of crop is farmed most frequently beside main crops in the field to attract insects. This additionally farmed crop is called trap strip. Trap strip prevents the infestation of insects on principal crops. Trap strips are very useful in dealing with the wheat stem sawfly. When solid stemmed plants are farmed around the wheat field, sawflies usually lay their eggs on the solid stemmed plant leaves in lieu of wheat leaves [31].

3.2.3 Fire

Farmers consider fire to destroy insect breeding grounds. Fire burns the soil-top and kills insects present there. However, firing may kill beneficiary insects as well. Besides, some larvae can sustain below the surface of the soil.

3.2.4 Temperature

Different thermal conditions can be used to kill insects or to prevent their infestation. Cold storage prolongs the shelf life of agro-products, and retards the development of pests. Heat treatment is also effective in killing insect larvae in certain types of products. Mangoes, for example, are submersed in hot water baths (at 115 °F for 68 min) in order to kill the eggs and larvae of fruit flies (Tephritidae) prior to export [32].

3.2.5 Radiation

Gamma radiation kills all stages of pests in storage conditions. This is a common method, which is employed to kill insects or insect larvae during export or import of large quantities of grains, fruits and vegetables.

3.2.6 Ultrasonic Vibrations

Moths are often sensitive to bats' ultrasonic signals, quickly escaping from the area. Imitation of the bat's echolocation system helps in driving away the lepidopterous insect pests from the area.

3.3 The Biological Alternatives

Biological alternatives can be used as a replacement of chemical pesticides to leave the ecosystem undisturbed. Biological alternative options can be broadly classified as: (a) Biological Control, (b) Biopesticides, (c) Semiochemicals, and (d) Transgenic Organisms [33]. Biological control, also known as biocontrol, is the use of natural enemies (predators, parasitoids, insects or other arthropod species) to reduce the damage caused by pests. Biopesticides, also known as biological control, are based on pathogenic microorganisms or natural products which usually kill pests. The term biopesticide may also be used, more widely, to describe the application of biological agents, pathogens, predators, or parasitoids. In addition, botanicals, semiochemicals and transgenic plants sometimes be described as biopesticides. According to the US Environmental Protection Agency (EPA), biopesticides are certain type of pesticides derived from natural materials such as animals, plants, bacteria and certain minerals.

3.3.1 Biological Control

Biological control involves the suppression of reproductive organisms through the actions of parasites, predators, or pathogens to restrict pest population at a lower average density [34]. There are three different approaches of biological control.

Importation Importation involves the enforcement of the natural enemies of a pest to a new locale where the pest does not inhabit naturally. The process involves determination of pest-origin and consequently collection of appropriate natural enemies associated with the pest. Selected natural enemies are then passed through rigorous assessments, testing and quarantine processes to ensure their appropriate use. Finally, the selected natural enemies are mass-produced and distributed [35]. To control pests most effectively, a biological control agent requires a colonizing ability, which will allow it to keep pace with the spatial and temporal disruption of the habitat. The control of a biological control agent over the pest will also be effective if the agent possesses temporal persistence. This ability enables the agent to maintain its population during the temporary absence of the target species. However, an agent with such attributes is likely to be non-host specific, which may unintentionally affect non-target organisms.

Augmentation Augmentation involves the supplemental release of natural enemies to boost up the natural inhabitant population. In addition, the cropping system may also be modified to favor or augment these natural enemies called as habitat manipulation. During the critical time of the season, a small number of natural enemies to pest is released, which is called inoculative release. *Encarsia formosa*, a parasitoid, is released periodically to control greenhouse whitefly which is an example of inoculative release. The predaceous mite, *Phytoseiulus persimilis*, is also used periodically to control two-spotted spider mite. On the contrary, inundative release means the release of millions of natural enemies. Lady beetles, lacewings, or parasitoids such as *Trichogramma* are frequently released in large numbers. Entomopathogenic nematodes are released at rates of millions and even billions per acre for controlling certain soil-dwelling insect pests [36].

Conservation In conservation method, biological control action is taken to enhance the effectiveness of existing natural enemies to pests in the ecosystem. As natural enemies are already adapted to the habitat and target pest, their conservation becomes simple and cost-effective. An example of such cost-effectiveness is growing nectar-producing crop plants in the borders of rice fields. These provide nectar to support parasitoids and predators of planthopper pests and thus effectively reduce pest densities by 10–100 folds. This also diminishes the necessity to spray insecticides by 70%, and consequently boosts overall crop yield by 5% [37].

Habitat manipulation is the modification of cropping system to favor natural enemies by providing a suitable habitat such as shelterbelt, hedgegrow, or beetle bank, where beneficial insects can live and reproduce. This can be done in several ways, such as [38]:

(a) Leaving a layer of fallen leaves or mulch provides a suitable food source for worms, and provides a shelter for small insects.
(b) Compost pile and containers for making leaf compost also provide shelter as long as they are accessible by animals.
(c) Artificial shelters in the form of wooden caskets, boxes or flowerpots can be undertaken, particularly in gardens to make a cropped area more attractive to natural enemies.
(d) Some types of birds in birdhouses eat certain pests. Attracting the most useful birds can be done by using a correct diameter opening in the birdhouse (just large enough for the specific species of bird that needs to be attracted to fit through, but not other species of bird). Besides facilitating natural or artificial housing, growing nectar-rich plants is also beneficial. Many natural predators are nectivorous during their adult stages, but are parasitic or predatory during larvae stage. Seeding of certain plants (*Helianthus spp*., *Rudbeckia spp*., *Dipsacus spp*., *Echinacea spp*.) is also advised to supply food for birds. Trees and shrubs, producing berries, also serve as food sources for the birds [35]. To avoide food competition, generally, human inedible berry trees are planted.

3.3.2 Biopesticides

Biopesticides are certain types of pesticides derived from natural materials such as animals, plants, bacteria, and certain minerals. For example, canola oil and baking soda have pesticidal applications and are considered as biopesticides.

Classification of Biopesticides Biopesticides fall into three major classes: (1) Microbial pesticides, (2) Plant-Incorporated-Protectants and (3) Biochemical pesticides or herbal pesticides [39].

1. *Microbial pesticides*, which consist of a microorganism (e.g. bacterium, fungus, virus or protozoan) as active ingredient, are used to control different types of pests. Each active ingredient is specific to its target pest. For instance, some fungi are capable of controlling certain weeds, while certain fungi are specific to kill insects. The most widely used microbial pesticides are subspecies and strains of *Bacillus thuringiensis* (Bt) [40].
2. *Plant-Incorporated-Protectants* (PIPs) are pesticidal substances, which are produced from the genetic materials of plants. These materials are produced by applying genetic engineering. For example, gene from the Bt pesticidal protein can be introduced into the genetic material of plant. The plant then produces substances that destroy the pests. The protein and its genetic material excluding the plant itself are regulated by regulatory bodies, such as the US EPA [41].
3. *Biochemical pesticides* or herbal pesticides are naturally occurring substances that control (or monitor) pests and microbial diseases. Conventional pesticides are generally synthetic materials that directly kill or inactivate the pest. Biochemical pesticides are often called botanical pesticides when they are derived from plant extracts. Biochemical pesticides include substances like insect sex pheromones and various scented plant extracts. Neem is one of the best known and most effective botanical pesticides. The active ingredient of Neem, azadirachtin, has the same activity as an insect hormone and disrupt moulting in a range of insect pests. Neem cake has multiple effects on the soil in controlling soil borne fungi and nematodes; the effects also last for the subsequent years [42]. Pyrethrin, extracted from chrysanthemum plants, is another highly effective botanical insecticide. Pyrethrin acts rapidly on insects causing immediate knock down [43].

Global market of Biopesticides About 1400 biopesticide products are being sold worldwide. At present, there are 68 biopesticide active substances registered in the EU and 202 in the USA. The EU biopesticides consist of 34 microbials, 11 biochemicals and 23 semiochemicals, while the USA portfolio comprises of 102 microbials, 52 biochemicals and 48 semiochemicals [44]. However, these biopesticide products represent only 2.5% of the total pesticide market. It is estimated that the biopesticides sector has been maintaining a compound annual growth rate of 16% in the recent years (compared with 3% for synthetic pesticides), and it is expected to become a market of $10 billion by 2017 [44, 45]. Table 2 enlists different types of botanical pesticides approved for use in different countries [2].

Market Trend of Biopesticides The global market for biopesticides was valued about US $1 billion in 2010, and it is expected to reach US $ 3.2 billion by 2017. On the other hand, the global market for synthetic pesticides was US $ 24 billion in 2010. From 2003 to 2010, global market for biopesticides has been increased by 56% (Fig. 1) [39, 46]. Increasing demand of residue-free crop production is one of the key drivers of the biopesticide market. High demand of organic food market and easier registration system than that of chemical pesticides are other important driving factors of enlarging biopesticide market.

Table 2 Botanical pesticides approved for use in specific countries [2]

	Pyrethrum	Rotenone	Nicotine	Neem	Others
Australia	✓	✓			Citrus oils
New Zealand	✓	✓		✓	
India	✓	✓	✓	✓	Ryania
Germany	✓			✓	
Brazil	✓	✓	✓	✓	
United States	✓	✓	✓	✓	
Canada	✓	✓	✓		
Mexico	✓	✓		✓	
South Africa	✓				

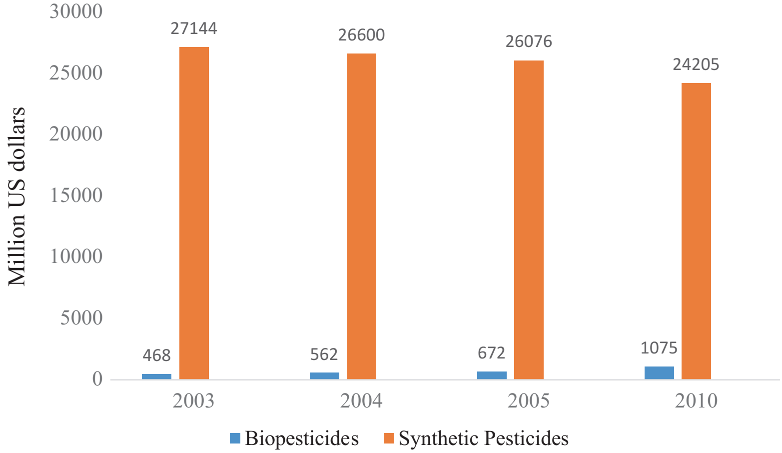

Fig. 1 Global biopesticides and synthetic pesticides market [46]

3.3.3 Semiochemicals

Semiochemicals (Greek word “semeon” means “signal”) are chemical substances that mediate interactions between organisms. Semiochemicals are attributed to interspecific and intraspecific interactions, which are categorized as allelochemicals and pheromones, respectively [47]. The allelochemicals are classified as allomones, kairomones and synomones. Allomones are often found in nature as part of a chemical defense, such as toxic insect secretions. Predators also use allomones to lure prey. Kairomones are a class of compounds that are advantageous for the receiver. The term “kairomone” is derived from the Greek word “kairos,” which means “opportunistic”. Kairomones benefit many predators and bugs by guiding them to prey or potential host insects. Synomones (from the Greek “syn” for “with” or “together”) are compounds that are beneficial to both the receiver and the sender [48]. Pheromones (Greek word “phereum” means “to carry”) are released by one member of a species to cause a specific interaction with another member of the same species. Pheromones may be further classified on the basis of the interaction mediated, such as alarm, aggregation or sex pheromone. It is the sex pheromones of insects that are of particular interest to agricultural integrated pest management (IPM) practitioners [49, 50].

The existence of pheromones has been known for centuries, apparently originated in observations of mass bee stinging in response to a chemical released by the sting of a single bee. The first isolation and identification of an insect pheromone (silkworm moth) occurred in 1959 by German scientists [50]. Since then, hundreds, perhaps thousands of insect pheromones have been identified by increasingly sophisticated equipment. Their main uses are to disrupt mating to restrict pest population growth, and to entrap pest species. Pheromone traps are often used with a fungal biopesticide, in which the lured individual gets infected and then released to spread the fungus to other healthy individuals.

3.3.4 Transgenic Organisms

Genes of one species can be modified or can be transplanted to another species. Organisms that have altered genomes are known as transgenic. Genetic modification with recombinant DNA techniques is the newest way of generating pest-resistant plants. The most successful commercial transgenic crops resistant to insects include cotton, maize and potato. These crops possess transgenes from the insecticidal bacterium *Bacillus thuringiensis* (Bt) and herbicide-resistant soybean [51–53]. Resistance against plant pathogens has been achieved by transferring genes from viruses into plants, bacteria, fungi, and other plants and insects [54, 55]. Herbicide-resistant transgenic crops, allow chemical weed control without harming the crop plant [56].

4 Integrated Pest Management (IPM)

Integrated Pest Management (IPM) aims to eliminate or drastically reduce the use of pesticides, and to minimize the toxicity of and exposure to any products which are used [57]. IPM utilizes a variety of methods and techniques, including chemical, cultural, biological, physical and mechanical strategies to control a multitude of pest problems. Non-integrated pest control programs tend to focus on killing pests, without taking into account the reason behind the pests' existence in the first place. On the other hand, IPM practitioners can better cure existing infestations and prevent future ones by removing or altering conducive conditions for pest infestations.

4.1 Working Principles of IPM Program

IPM is not a single pest control method; it is a series of pest management evaluations, decisions and controls. Growers practicing IMP are reported to follow a four-tiered approach [58]. The four steps include:

1. *Setting Action Thresholds* – Before taking any pest control action, IPM programs set an action threshold point at which pest populations or environmental conditions indicate that pest control action must be taken. Sighting a single pest does not always mean that control is needed. The level at which pests will either become an economic threat is critical to guide future pest control decisions [58].
2. *Monitoring and Identifying Pests* – All insects, weeds, and other living organisms may not require control. Many organisms are innocuous, and some are even beneficial. IPM programs work to monitor for pests and identify them accurately, so that appropriate control decisions can be made in conjunction with action thresholds. This monitoring and identification process eliminates the possibilities of unnecessary and inappropriate pesticide usage [58].
3. *Prevention* – As a first line of pest control, IPM programs work to manage the crop, lawn, or indoor space to prevent pests from becoming a threat. In an agricultural crop, this may mean using cultural methods, such as rotating between different crops, selecting pest-resistant varieties, and planting pest-free rootstock. These control methods can be very efficient, cost effective, and present little to no risk to people or to the environment [58].
4. *Control* – Once monitoring, identification, and action thresholds identify the necessity or improvement of pest control method, IPM programs then evaluate the proper control method both for effectiveness and risk. Effective techniques with minimum risk are preferred, which include targeted chemicals (pheromones to disrupt pest mating), or mechanical control (trapping or weeding). Additional pest control methods, such as targeted spraying of pesticides, are only employed only if monitoring, identifications and action thresholds indicate that lower risk controls are not working [58].

4.2 Advantages and Disadvantages of IPM Program

IPM program is a cost effective method, and easy to implement [59]. In IPM programs, chemical pesticides are used only when needed and in combination with other approaches for more effective and long-term control. In addition, pesticides are selected and applied in a way that minimizes their possible harm to people and the environment, thus reducing pesticide residue hazards. IPM makes full use of environmentally sound control methods, which diminishes chances of contamination and worker health problems. An increase in yield due to integrated pest management also facilitates the economic benefits. Figure 2 shows different benefits of IPM programs [60].

There are also certain drawbacks of IPM programs. An IPM program requires a higher degree of management, which includes attention to field histories to anticipate pest problems. Besides, selecting crop varieties and choosing tillage system that will suppress anticipated pest damage while generating the highest yield potential are other commercial factors. Thus, IPM approach is much labor intensive; success of the approach is also weather dependent.

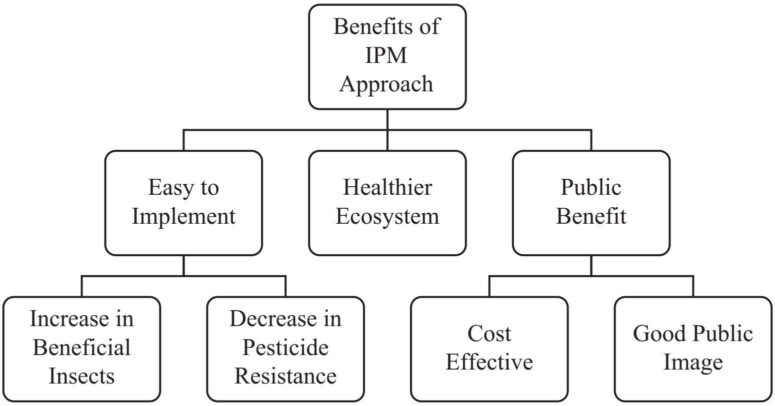

Fig. 2 Benefits of IPM Program [60]

5 Conclusion

Extensive use of pesticides has caused food and groundwater contaminations, and destruction of beneficial insects. Pesticides have been linked to a number of health problems, including neurologic and endocrine (hormone) system disorders, birth defects, and cancer. Increased understanding and awareness of the adverse effects of pesticides on health and environment is driving the demand for alternatives of pesticides. There are proven alternatives to pesticide use. These 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. Many sustainable farms use Integrated Pest Management (IPM) as an alternative to pesticides. IPM is a growing movement among farms of all sizes that incorporates a variety of techniques to eliminate pests, while minimizing environment damage. An IPM farm may grow pest-resistant crop varieties, use predatory insects to kill plant-eating pests, employ mechanical pest traps, crop rotation and vegetational biodiversity. IPM program also call for determining if pests are actually causing or are likely to cause damage to health or crops, and, if they are, whether the extent of damage warrants action. Because of versatility and cost effectiveness, IPM can be a suitable choice for most of the developing countries as an alternative of pesticides.

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Prospects of Organic Farming

B. Suresh Reddy

1 Introduction

Green Revolution (GR) technologies, supported by policies, and fueled by agrochemicals, machinery and irrigation, are well known for its enhanced agricultural production and productivity. While these technologies greatly helped to address food security and food sovereignty needs, farmers using these technologies, have to depend on external inputs which constitute the major cost of production for small-holder farmers. The manufacture of fertilizers and pesticides, the two major inputs of GR technologies, needs fossil fuels and/or expensive energy, and these are associated with serious environmental and health issues. It is perhaps owing to these input issues and their negative impacts the Intergovernmental Panel on Climate Change (IPCC) has noted that agriculture as practiced today (GR agriculture), accounts for about one fifth of the projected anthropogenic greenhouse effect. This will produce about 50% of CH_4 and 70% of N_2O of overall emissions.

Modern agricultural farming practices and irrational use of chemical over the last four decades resulted in loss of natural habitat balance, loss of soil health and caused many hazards such as soil erosion, decreased ground water level, soil salinisation, pollution due to use of fertilisers and pesticides, genetic erosion, ill effects on environment, reduced food quality and increased the cost of cultivation, making the farmer poorer from year to year [1–4]. In farming, pest management is an important aspect that needs to be addressed always. Globally about 50% of all food and cash crops are lost to pre- and post-harvest pests [5]. Even in India, with the existing protection levels, based on significant advances in crop protection research during the past 40 years, still about 30% of the pre-harvest crop yield worth Rs. 45,000 crore is lost annually [6]. The use of pesticides in modern farming practices for

B. Suresh Reddy (✉)
Division for Sustainable Development Studies (DSDS), Centre for Economic and Social Studies (CESS), Begumpet, Hyderabad, Telangana, India
e-mail: srihithasuresh@yahoo.com

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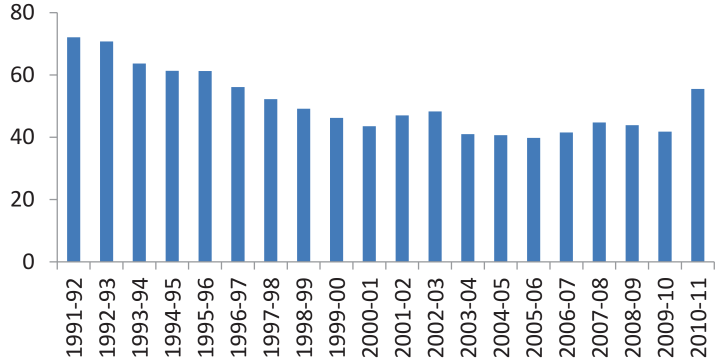

Fig. 1 Consumption of pesticide (technical grade) in India in 000' tonnes (Source: Ministry of Agriculture, GOI [11])

obtaining increased yields has been viewed as a sine qua now for the success of the agricultural sector. However, most of the pesticides may affect non-target organisms, contaminating soil and water [7]. The pesticide consumption in India has increased from 434 metric tonnes in 1954 to over 55,540 metric tonnes in the year 2010–11 (see Fig. 1) accounting for 30% of the cropped area. Today, pesticide consumption in India is less than 1 kg/ha as against 4.5 kg/ha in USA and 11 kg/ha in Japan [8]. Therefore, an indiscriminate use of pesticides has led to a number of environmental problems [1, 2]. According to Mancini et al. [9], in India, 60% of all the pesticides is applied to cotton crop, accounting for only 4% of the total cropped area. It is alarming to note that about 17.53% of the total pesticides are used only in Andhra Pradesh (A.P.) Thus remaining as the largest consumer of pesticides in the country followed by Uttar Pradesh and Maharashtra states as second and third largest consumers at 16.68 and 12.68% respectively.

As a result of all these higher investments, farmers find that agriculture is no more a viable proposition and in fact, a large number of farmers are in stress [10]. Perhaps shooting up of price of factory made external inputs and the government slow withdrawal of investment as well as market intervention and more significantly, shifting of subsistence farming (mainly with homegrown inputs) to commercial farming (largely with purchased inputs) would have also contributed for the present crisis. In other words, the local indigenous farm techniques are being wiped out and replaced by modern techniques, thus resulted unviable and unsustainable farm enterprise [11]. It is in this context that alternative farm techniques and strategies for growing crops ought to be found in the larger interest. Owing to the merits of organic cultivation as compared to modern agricultural practices, such principle is attracted across the world. Many state supported agencies, Non-Governmental Organizations (NGOs) and individuals started experiments on organic methods of food production in the recent past.

The popular and most accepted definition of organic farming is, "organic agriculture is a holistic production management system which promotes and enhances agro-ecosystem health, including biodiversity, biological cycles, and soil biological activity. It emphasizes the use of management practices in preference to the use of off-farm inputs, taking into account that regional conditions require locally adapted systems. This is accomplished by using where possible, agronomic, biological and mechanical methods, as opposed to using synthetic materials, to fulfil any specific function within the system", [12]. The term "conventional farming" refers to a production system which employs a full range of pre- and post-plant tillage practices (e.g, plough, discplant, cultivate), synthetic fertilizers and pesticides. Conventional agriculture basically refers to a system of agriculture, where chemicals are used in cultivation of crops. It is characterized by a high degree of crop specialization. By contrast organic farming is characterized by a diversity of crops.

Organic farmers rely on natural farming methods and modern scientific ecological knowledge in order to maximize the long-term health and productivity of the ecosystem, thus enhance the quality of the products and protect the environment. Proponents of organic methods believe that it is a more sustainable and less damaging approach to agriculture [13]. Organic agriculture has its roots in traditional agricultural practices in small communities around the world. Farmers passed down knowledge of effective practices onto subsequent generations. Organic agriculture became visible on a wider scale in the 1960s, when farmers and consumers became concerned on the amount of chemicals used in crop and animal production. Since then, it has developed into a more cohesive and organized movement and it is now the fastest growing food sector globally.

As organic foods cannot be distinguished from conventional products at a glance, consumers depend entirely on third-party certification, i.e. the process according to which public or private certification bodies provide assurance that organic products have been produced and handled according to applicable standards. Organic standards have long been used to represent a consensus about what an "organic" claim on a product means, and to convey that information to consumers. Certification not only leads to consumer trust in the organic system and products, but also gives organic farming a distinct identity and makes market access easier. Thus, in contrast with food labelled as "environment-friendly", "green" or "free range", the organic label denotes compliance with very specific production and preparation methods. If farmers use the organic label, they must receive certification that the product complies with applicable standards following third-party inspections of their operations. Organic standards usually include the use of only natural agricultural enhancers, conservation of natural resources, maintenance of biodiversity and preservation of the ecosystem. Owing to the fact that organic farmers must take into account their impact on their immediate ecosystems, these methods are generally adapted to local conditions.

Overall, the benefits of organic agriculture are expected to be environmental, social and economic. After reviewing these benefits in further detail, the history of the organic movement and of the work of the Food and Agriculture Organization of the United Nations (FAO) on organic agriculture will be briefly outlined in order to provide a background to this study on national legislation on organic agriculture.

2 Background

Literature review has revealed that opinions about organic farming are divided, especially among the experts. Disagreements about the profitability and yield increase in organic farming are acute, but there is a strong consensus on its eco-friendly nature and inherent ability to protect human health. There are strong views against organic farming, mainly on the grounds of practicability of feeding a billion people, its financial and economic viability, availability of organic inputs and the know-how. However, many studies revealed that organic agriculture is productive and sustainable [14–18]. There are also many people approve organic agriculture, advocate a careful conversion of farms into organic, so that yield loss is taken care of to the greatest extent possible. Presently, there is a lack of government subsidies or support to make the conversion to organic easier or cheaper. Questions about the yield and financial viability of organic farming are crucial and there are no empirical studies available in the Indian context comparing the economic and ecological returns of organic farms vis-à-vis conventional farms. This chapter is an attempt to fill this gap. It attempts to bring together different issues in the light of recent developments in organic farming. It traces the history of organic farming and reviews the global and Indian scenario with reference to organic farming. Based on the quantitative and qualitative research done with small and marginal farmers in Andhra Pradesh state of India, this analyses the economic and ecological returns of organic farming vis-à-vis conventional farming and there by contributes to overall policy discourse on organic farming for better micro-level interventions.

This chapter has been organized into six sections including this introduction. Section "Background" presents history of organic farming, status of organic farming at global, national and state level. Third section is on study area, data and methodology of the study. Socio-economics and ecological aspects of organic farmers are discussed in comparison with conventional farmers in section "Empirical Results". Farmers' perception on organic farming is presented in section "Organic Farming: Farmer's Perceptions". In the last section, some Conclusions are made based on the empirical evidence.

2.1 History of Organic Farming

Organic farming or natural farming has no doubt emerged from Asian countries like India and China, where agriculture has been the mainstay of people and farmers have nurtured and groomed this art over several centuries. However the organic movement as such began as a reaction of agricultural scientists and farmers against the industrialization of agriculture. Advances in biochemistry, (nitrogen fertilizers) and engineering (the internal combustion engine) in the early twentieth century led to profound changes in farming. Plant breeding produced hybrid seeds. Fields grew in size and cropping became specialized to make efficient use of machinery and reap the benefits of the green revolution. Technological advances during World War II spurred post-war innovation in all aspects of agriculture, resulting in such advances as large-scale irrigation, fertilization, and the use of pesticides. Ammonium nitrate, used in munitions, became an abundantly cheap source of nitrogen. DDT, originally developed by the military to control disease-carrying insects among troops, was applied to crops, launching the era of widespread pesticide usage.

Gustav Simons [19] wrote an important book on the relationship between the health of soils, growth of plants and the health of mankind. In Germany, Rudolf Steiner's Spiritual Foundations for the Renewal of Agriculture [20], led to the popularization of biodynamic agriculture. The term organic farming was first used by Lord Northbourne. The term is derived from his concept of "the farm as organism" and which he expounded in his book, Look to the Land [21], wherein he described a holistic, ecologically balanced approach to farming. The British botanist, Sir Albert Howard often referred to as the father of modern organic agriculture worked as an agriculture advisor during 1905–1924 in Pusa, Samastipur, India, where he documented the traditional Indian farming practices. He regarded such practices as superior to modern agricultural science. His research and further developments of these methods was recorded in his book, "An Agricultural Testament" [22], which influenced many scientists and farmers of the day. He adopted Northbourne's terminology in his book, "The Soil and Health: A Study of Organic Agriculture" in 1947.

In 1939, Lady Eve Balfour established the pioneering Haughley Experiment on her Suffolk farmland in England and continued for more than 40 years. It was the first scientific comparison of organic and conventional farming. Lady Eve Balfour, shared some of her experiences in a book called the Organics classic: The Living Soil. Japanese farmer and writer, Masanobu Fukuoka, invented a no-till system for small-scale grain production in the early 1940s and called it "Natural Farming". In the post-world war era, the green revolution launched in Mexico with private funding from the US, encouraged the development of hybrid plants, chemical controls, large-scale irrigation, and heavy mechanization around the world. Although science tended to concentrate on new chemical approaches, sustainable agriculture was the topic of interest. In the US, J. I. Rodale [23] began to popularize the term and methods of organic growing, particularly through promotion of organic gardening. Carson [24], a prominent scientist and naturalist, published *Silent Spring*, describing the adverse effect of DDT and other pesticides on the environment, launching the worldwide environmental movement. By the 1970s, global movements concerned with pollution and the environment increased their focus on organic farming.

In 1972, the International Federation of Organic Agriculture Movements (IFOAM), was founded in Versailles, France. It is an umbrella organisation for organic agriculture which developed international basic standards for organic agriculture and went to establish IFOAM accreditation programme (1992) to accommodate certifying agencies and set up international organic accreditation service [25]. IFOAM is dedicated to the diffusion of information on the principles and practices of organic agriculture across national and linguistic boundaries. Fukuoka released his first book, *One Straw Revolution* (1975) with a wide ranging impact on the agricultural world. In the 1980s, various farming and consumer groups worldwide began pressing for government regulation of organic production. This led to legislation and certification standards being enacted beginning in the 1990s. In the year 1991, European Union regulations gave guidelines for the production of organic crops in the European community. Similarly in the year 1999 a joint FAO/WHO intergovernmental body produced a set of guidelines for organic production. Since the early 1990s, the retail market for organic farming in developed economies has grown by about 20% annually due to increase consumers' demand. Though small independent producers and consumers initially drove the rise of organic farming, as the volume and variety of "organic" products grows, production will increasingly be large-scale.

2.2 Global Status of Organic Farming

Organic agriculture is developing rapidly and today at least 170 countries produce organic food commercially. There were 43.1 million hectares of organic agricultural land in 2013, including in conversion areas [26]. As per Fig. 2, the regions with the largest areas of organic agricultural land are Oceania, (17.3 million hectares), Europe (11.5 million hectares), Latin America (6.6 million hectares) and Asia

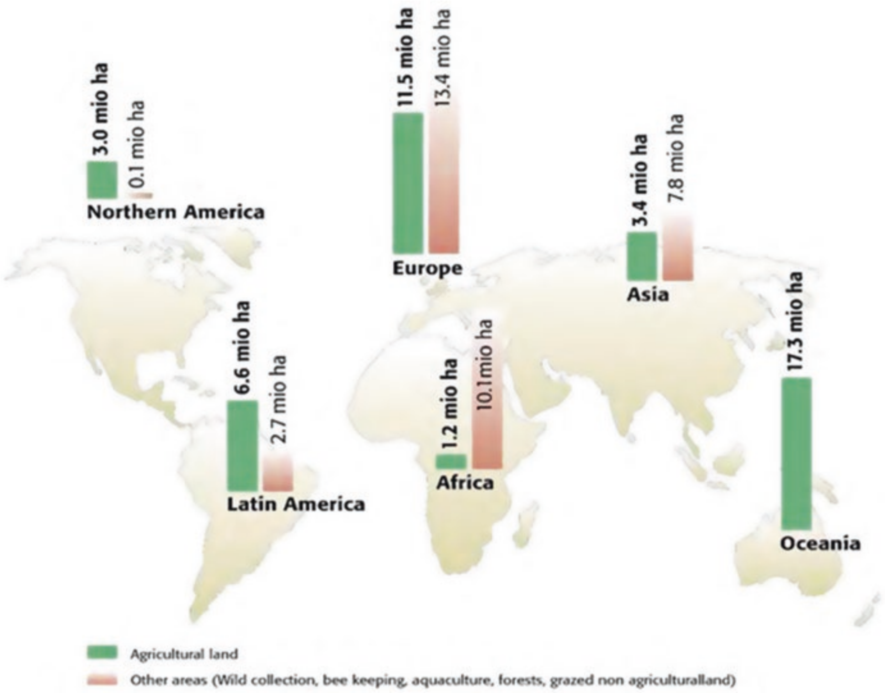

Fig. 2 Agricultural land and wild collection areas in 2013 (Source: FiBL/IFOAM (2015)) [27]

(3.4 million hectares, 8%), North America (3 million hectares, 7%) and Africa (1.2 million hectares, 3%). In Europe, organically managed land increased by 0.33 million hectares (+ 4%) and by 0.18 million hectares (+27%) in Africa [28]. There were almost 2 million producers in 2013. Thirty six percent of the world's organic producers are in Asia, followed by Africa (29%) and Europe (17%). The countries with the most producers are India (650,000), Uganda (189,610), and Mexico (169,703). Global sales of organic food and drink reached 72 billion US dollars in 2013. Revenues have increased almost fivefold since 1999. In Europe, organically managed land increased by 0.33 million hectares (+ 4%) and by 0.18 million hectares (+27%) in Africa. In India, only 0.03% of the area is under organic farming, though there is huge scope for bringing more and more land under organic farming [26].

2.3 Organic Farming in India

India has traditionally practiced organic agriculture, but the process of modernization, particularly the green revolution, has led to the increased use of chemicals. In recent years, however, limitations of agriculture based on chemical use and intensive irrigation have become apparent and there has been a resurgence of interest in organic agriculture. Renewed interest in organic agriculture is mainly due to two concerns, falling agricultural yield in certain areas as a result of, *inter alia* excessive use of chemical inputs, decreased soil fertility and environmental concerns. Exports also played a role but perhaps lesser than in other countries.

The 10th five year plan encouraged the promotion and encouragement of organic farming using organic waste, Integrated Pest Management (IPM) and Integrated Nutrient Management (INM) [29]. Even the 9th five year plan had emphasized the promotion of organic produce in plantation crops, spices and condiments using organic and bio-inputs for the protection of environment and promotion of sustainable agriculture [25]. There are many state and private agencies involved in promotion of organic farming in India. These include several ministries and government departments at both central and state levels, universities and research centres, NGOs like Navadanya, Deccan Development Society, Key Stone Foundation, AME, TIMBAKTU Collective and Organic Farming Association of India and producers organizations and certification bodies besides various processors and traders.

The Government of India has also launched the National Programme for Organic Production [30]. The national programme involves the accreditation programme for certification bodies, norms for organic production, promotion of organic farming etc. The NPOP standards for production and accreditation system have been recognized by the European Commission and Switzerland as equivalent to their country standards. Similarly, the United States Department of Agriculture (USDA) has recognized NPOP conformity assessment procedures of accreditation as equivalent to those in the US. With these recognitions, the Indian organic products duly certified by the accredited certification bodies of India are accepted by the importing countries.

Currently, India ranks 33rd in terms of total land under organic cultivation, and 88th in agricultural land under organic crops to total farming area. According to the Agricultural and Processed Food Product Export Development Authority (APEDA), the cultivated area under certified organic farming has grown almost 17-fold in last one decade, i.e. from 42,000 ha in 2003–04 to 7.23 lakh ha in 2013–14. As on March 2014, India has brought 4.72 million ha area under organic certification process, which includes 0.6 million ha of cultivated agricultural land and 4.12 million ha of wild harvest collection area in forests. An estimated 69 million hectares, however, are traditionally cultivated without using chemical fertilizers and could be eligible for certification under the current practices, or with small modifications. Certifying these farms remains a challenge, however, as many of these farms are small holdings (nearly 60% of all farms in India are less than 1 ha). Small-scale, poor farmers may be unable to afford the cost of certification, they may be illiterate and unable to maintain necessary records, or may be using indigenous cultivation systems not recognized in organic certification systems. These farms mainly produce for home consumption, and to supply the local markets in case of irregular surpluses. Such barriers pose difficulties for farms to reap potential benefits of organic certification.

The current market for organic foods in India is pegged at Rs. 2500 crore, which according to ASSOCHAM, is expected to reach Rs. 6000 crore by 2015. Domestic market is also growing at an annual growth rate of 15–25%. As per the survey conducted by ICCOA, Bangalore, domestic market during the year 2012–13 was worth INR 600 crore. Thus, a huge potential is seen in the nascent Indian organic sector. Organic products, which until now were mainly being exported, are now finding consumers in the domestic market also. The current status (data) of organic farming in India is given in Table 1.

India produced around 27,132,966 MT (Table 2) of certified organic products including all varieties of food products namely Basmati rice, pulses, honey, tea, spices, coffee, oil seeds, fruits, processed food, cereals, herbal medicines and their

Table 1 Details of data with respect to organic products in India during the year 2012–13

Number of products exported	135
Total quantity exported	165,262 metric tones
Value of total export	US$ 374 million
Total certified area (including under cultivation, forest and wild harvest)	5.21 million hectare
Organic crops/ commodities/products produced in India	Sugarcane, cotton, basmati rice, pulses, tea, spices, coffee, oil seeds, fruits and their value added products, organic cotton fiber, functional food products etc.
Countries importing Indian organic products	EU, US, Switzerland, Canada, South East Asian countries and South Africa
Share of Indian organic products in export	Oil seeds – soybean (41%) lead among the products exported followed by cane sugar (26%), processed food products (14%), basmati rice (5%), other cereals & millets (4%), tea (2%), spices (1%), dry fruits (1%) and others

Source: APEDA [31]

Table 2 Export of organic products by APEDA for the year 2014–15

Particulars	Quantity in metric tonnes	Value in lakhs
Floriculture	35,446.58	88,781.03
Fresh fruits and vegetables	2,500,961.88	7,47,413.65
Processed fruits and vegetables	1,006,679.44	6,67,035.89
Animal products	2,163,060.54	3,312,830.32
Other processed foods	3,012,631.55	2,489,305.42
Cereals	18,414,186.79	5,827,979.92
Total	27,132,966.78	13,133,346.23

Source: DGCIS Annual export, Govt. of India [32]

value added products. This production is not just limited to the edible sector; it includes organic cotton fiber, garments, cosmetics, functional food products, body care products, etc. India exported 86 items last year (2014–15) – a total volume of 27,132,966 MT. The export realization was around US $ 19,847 millions. Organic products are mainly exported to EU, US, Australia, Canada, Japan, Switzerland, South Africa and the Middle East.

The states of Uttaranchal and Sikkim have declared their states as organic states. In Maharashtra, since 2003, about 500,000 hectares has been under organic farming (of the 1.8 crore ha of cultivable land in the state). Organic cotton production was concentrated in low productivity and high uncertainty areas such as Vidarbha, since the early 1990s. The Vidarbha Cotton Growers' Association, set up in 1994 with 135 members, has tied up with international agencies for exports (GOI 2001). In Gujarat organic production of chickoo, banana and coconut was found to be more profitable, though field crops and mango had both lower input costs as well as yields [33]. In Karnataka by the year 2005, 1513.25 hectares was under certified organic farming, and while 4750.00 hectares was under non-certified organic farming. Groundnut, jowar, cotton, coconut and banana are being grown under organic conditions-the major reasons for shift include sustained soil fertility, reduced cost of cultivation, higher quality of produce, sustained yields, easy availability of farm inputs and reduced pest and disease attacks. The Government of Karnataka released a state organic farming policy in 2004. Most of the area in the north eastern states is being used for organic farming. In Nagaland, 3000 hectares are under organic farming with crops like ginger, Soya bean, kholer, maize, large cardamom, passion fruit and chilly. The state of Rajasthan has more than 6000 hectares under organic farming. States like Tamil Nadu, Kerala, Madhya Pradesh, Himachal Pradesh and Gujarat are promoting organic farming vigorously.

Farmers' organizations, such as Chetana have been established for marketing organic products. This programme was implemented in three states: Andhra Pradesh (Asifabad and Karimnagar), Maharashtra (Vidarbha, Akola and Yavatmal) and Tamil Nadu (Dindigul and Tuticorn). The programme was started in the year 2004 with 240 farmers and by the year 2007 more than 5500 farmers were participating in the program. A total of about 20,000 acres and total raw cotton yield of 5000 tons was expected, which means about 1700 tons of lint. Food crop yield was 8000 metric tons, mainly pulses. The farmers have to face several problems while converting from conventional farming to organic. Lanting (2007) identified some of them as follows: premium price is not paid for these products because they are in the transition stage, storage facility is needed, with cash paid (preferably 70% of the crop value) for the stored products [34]. Rural banking should be strengthened and loaning process should be made simpler. Hence the government could give a helping hand in the first 3 years of changing over to organic farming by providing preferred access to organic farmers. This could help to reduce the dropout rate.

Sanghi [35] argues that organic farming is an intensive process, mostly limited to resource rich farmers, and the export market and depends heavily on external support systems for price, market intelligence and certification of produce, among others. Hence he says that the scope of coverage and social relevance of the organic farming is also limited. Instead he proposes ecological farming whose main objectives are maintenance of high productivity, reduction in production cost and enhancement of self-reliance. It caters to both the poor-resource and the rich-resource; the process is simple, addresses local market and the scope of coverage and social relevance is also high. There are four main steps in ecological farming: the first being the adoption of non-chemical pest management methods; the second step is to focus on selling pesticide-free produce in the local market; the next step is to establish community managed seed banks; and finally the fourth step is to adopt non-chemical method of nutrient management. It has been argued that the ecological method is indigenous but is gradually disappearing due to constraints in labour availability. Sanghi sees a great scope for its revival by utilizing the incentives of labour under the National Rural Employment Guarantee (NREG) act.

2.4 Organic Agriculture in Andhra Pradesh

In A.P, in the early 1980s, the Permaculture Association of India popularized the concept of 'Permaculture' (permanent agriculture). Permaculture is the conscious design and maintenance of agriculturally productive ecosystems which have the diversity, stability, and resilience of natural ecosystems. It is the harmonious integration of landscape and people providing their food, energy, shelter and other material and non-material needs in a sustainable way. The philosophy behind Permaculture is one of working with, rather than against, nature; of protracted and thoughtful observation rather than protracted and thoughtless action; of looking at the systems in all their functions, rather than asking only one yield of them; and of allowing systems to demonstrate their own evolutions [36]. The Deccan Development Society (DDS) an internationally well known NGO working with dalit women groups, has developed a farm on the principles of Permaculture in Zaheerabad region of deccan area. DDS encouraged sustainable agricultural practices in a big way and has been a pioneer in the country. More than 5000 women farmers in an area of more than 20,000 acres adopt sustainable agricultural practices, which are environment friendly, and are based on the traditional knowledge and are environment friendly. Similarly, the Centre for Sustainable Agriculture (CSA) based at Hyderabad, through several NGOs in the state, has promoted non-pesticidal management of pests in the state, where in the use of pesticides and chemical fertilizers is discouraged, while the use of local resources is encouraged. The small success from few villages could be scaled up into more than 7 lakh acres in last 3 years in 1500 villages benefiting more than 3 lakh farmers. The Community Managed Sustainable Agriculture program is being implemented by the Society for Elimination of Rural Poverty, the Government of Andhra Pradesh and the, Sustainable Agriculture Network of NGOs, with technical support from the Centre for Sustainable Agriculture. Today there are 50 villages which have become pesticide free and seven villages which have become completely organic. The concept of non-pesticidal management of pests is being promoted among the farming community through the Indira Kranthi Pathakam of the Government of Andhra Pradesh. The Timbaktu Collective is another organization which has been promoting organic farming practices since a long time in Ananthapur district. Timbaktu Organic was initiated in 2005 by Timbaktu Collective in association with Adisakthi, Ananthasakthi and Mahilasakthi Mutually-aided Thrift Co-operative Societies (MATCS) promoted by the Collective, with financial support from Sir Dorabji Tata Trust, Mumbai. The goal of this venture is that the small and marginal farmers of the area improve their livelihood on a sustainable basis using organic farming.

The Government of Andhra Pradesh has initiated programmes related to organic farming through the Department of Agriculture and Horticulture. The Agriculture Department is proposing to take up promotion of organic farming in the state during the year 2008–09 by implementing several schemes with an outlay of Rs. 18.29 crores. These schemes include organization of vermicompost units, establishment of vermi-hatchery units, distribution of green manure seed on subsidy, supply of bio-fertilizers on subsidy and certification of organic farming. The Andhra Pradesh state's policy on organic farming is yet to be finalized and the draft developed in this regard is being discussed at various levels.

Similarly the Horticulture Department of A.P is implementing the organic farming scheme under the State Horticulture Mission (SHM) from the financial year 2008–09. To get the certification, the organic farming scheme is proposed to be implemented in 12 districts of A.P. in the coming 3 years. These include Ranga Reddy, Medak, Mahbubnagar, Nalgonda, Warangal, Khammam, Kurnool, Kadapa, Guntur, Prakasam, Chittoor and Paderu ITDA and Vishakhapatnam. The organic farming scheme is being implemented in an area of 6567 hectares by selecting clusters of 50 hectares in compact blocks. The crops covered under the scheme include chillies, ginger, mangoes, cashew and vegetables. As per the SHM guidelines, the assistance per cluster is Rs. 9 lakhs. Over a period of 3 years, all the farmers will be formed into groups, and trainings will be provided by experienced persons and personnel of the certification agency. The NGOs are actively participating in the scheme; they are responsible for obtaining certification by the accredited certification agency with whom the agreement is entered. All the NGOs except Pilupu (in Ranga Reddy district) have entered into an agreement with M/s Vedic Organic Certification Agency. The SHM is providing an assistance of upto Rs. 15,000 per hectare over a period of 3 years. Rs. 7000 is given in the initial year followed by Rs. 4000 each in the second and third years to each farmer upto a maximum of 4.00 hectares per farmer. A technical support group member is allotted to one or two districts for monitoring the scheme periodically. The NGO shall identify the traders to market the organic produce at a higher price. Acharya NG. Ranga Agricultural University is also conducting comparative research between organic farming and conventional farming since 2007 Rabi (last three crops) in all its research stations in the state. Each research station is conducting trials on the predominant crop grown in that area.

3 Case Study of Andhra Pradesh

The state of Andhra Pradesh (undivided state: in 2014 it was bifurcated into Telangana and Andhra pradesh) chosen for the study is the fifth largest state in India in terms of both surface area and population. Based on physiographic, soil types, crops and cropping pattern, the state has been divided into nine agro climatic zones, namely, high altitude and tribal zone, North coastal zone, Godavari zone, Krishna zone, Southern zone, Northern Telangana zone, Central Telangana zone, Southern Telangana zone and Scarce rainfall zone.

Andhra pradesh state is richly endowed with natural resources and has a geographical area of 274.40 lakh hectares and an estimated population of 8.46 crore [37]. The population of SCs and STs constitute 16.41 and 7.0% respectively. The overall literacy rate in A.P, as per 2011 Census, is 67% as against the literacy rate of 74% at all India level. The average land holding size in the state during 2011–12 is 1.08 hectares. About 70% of the state's population is engaged in agriculture. Over 80% of those involved in agriculture are small and marginal farmers and landless labourers who own a mere 35% (3.5 million hectares) of the total 10 million hectares of cultivated land. About 24.49 million bovines (cattle and buffaloes), 35.16 million sheep and goats, 0.75 million pigs and 123 million poultry are distributed across some 10 million households engaged in agriculture. Andhra Pradesh has the distinction of being home to most of the diversified livestock resources across nine agroclimatic zones with different production systems. Livestock farming is one of the most sustainable and dependable livelihoods options as an alternate to their dependable resources in rural areas, especially for small and marginal farmers and agricultural labourers who hold 70% of the total livestock resources and 20% of the total land holdings. Small ruminants and backyard poultry are reared primarily by the landless adivasi, the traditional small-ruminant farming castes such as kurma, golla, and dalits. The size of bovine herd is closely linked to private land ownership, with the number of bovines increasing with land holding size. In all agricultural settings across AP, women play a greater role than men in agriculture-related activities work and food preparation besides looking after almost 80% of the day-to-day livestock management. The net area sown for 2011–12 was 111.60 lakh hectares constituting about 40.57% of its total geographical area. Similarly the state has about 62 lakh hectares of forest area. Gross area irrigated in A.P during the year 2011–12 was 67.85 lakh hectares. Wells account for a major share of 25.44 lakh hectares (50.0%) followed by canals for 18.17 lakh hectares (35.71%) and 5.49 lakh hectares under tanks (10.79%). A highest ever priority has been accorded to the development of irrigation infrastructure in backward and drought prone regions of the state. The state government has initiated a historical mission named 'JALAYAGNAM' with the aim of completing 86 projects (44 Major, 30 Medium, 4 Flood Banks and 8 Modernization) in a record time. These projects are expected to create a new irrigation potential of 97.07 lakh acres besides stabilizing 22.53 lakh acres. The state also has initiated a project for encouraging micro irrigation systems for achieving water use efficiency. The area under micro-irrigation systems for the year 2011–12 comes to 8.95 lakh hectares.

The average annual rainfall of the state amounts to 830 mm, the range being 690 mm (Rayalseema region) to 950 mm (coastal Andhra). While the average annual rainfall of Telangana region in the state is 860 mm. Cereals and millets account for a lion's share under food crops (38.94% of the total area) followed by commercial crops (20.19%), oil seeds crops (14.09%) and pulses (14.02%). Rice under cereals; groundnut, sunflower and castor under oil seeds, cotton, chillies and sugarcane under commercial crops; and Bengal gram, blackgram, redgram and green gram under pulses constitute the major crops grown in the state, whereas an area of 25.59 lakh hectares is under various horticultural crops. Mango and sweet orange occupy a predominant position in acreage under fruits besides vegetables and flowers.

Anantapur district in Andhra Pradesh has high inter-annual variations in precipitation. Normal rainfall of the district averages 552 mm (see Table 3) which is bound to influence crop yields of the region. Most of the rainfall is received during June to September, although recently rainfall has become unreliable with a distribution is highly erratic distribution. The soils are mainly shallow, barren, sandy and only marginally fertile. The district is primarily characterised by rainfed agriculture. Most farmers are 'small and marginal' and grow a wide variety of both food and commercial crops (Oil seeds, pulses, millets and fibre crops) under dryland farming practices. Agriculture in Anantapur district of Rayalseema is practised on degraded and infertile soils with a majority of them being sandy soils. A large percentage of area is under groundnut. An erratic and deficient rainfall, rising costs of cultivation coupled with low market prices have led to a severe problem of indebtedness among farmers.

Interestingly, Anantapur has the least area under irrigated rice and highest rural livestock population in Rayalseema region. Large flocks of goat and sheep are managed extensively in the district. Certain parts of the district have a significant population of Adivasis (known as Scheduled Tribes), who happen to be among the most marginalised sections of the Indian society.

This study used an *ex post facto* research design. Both qualitative and quantitative methods were used for assessment of economic and ecological returns from millet-based bio-diverse organic farms vis-à-vis conventional farms. It used both

Table 3 Basic features of the selected state and district for the year 2011–12

Particulars	Andhra Pradesh	Anantapur district
Area in sq.km	274.40 lakh sq.km	19,130 sq.km
Normal rainfall (mm)	720.4	552
Population in lakh nos.	846.66	40.83
(a) Male	425.10	20.64
(b) Female	421.56	20.18
Literacy rate (per cent)	67.02	64.28
(a) Male	74.88	74.09
(b) Female	58.68	54.31
Average operation land holding (in hectares)	1.08	1.76
Gross cropped area ‘000 ha	13,759	1114.0
Gross irrigated area ‘000 ha	6785	171.9
Percentage of net irrigated area	45.60	15.43
Food grains production In ‘000 tonnes(2011–12)	18,402	298.0
Food grain yield in kgs per hectare(2011–12)	2588.7	1059.1
Total livestock population (numbers as per 2007 census)	60,200,863	5,517,104

Source: Bureau of Economics and Statistics (BES), Hyderabad; Government of A.P, 2013 and Director of Animal Husbandry, Andhra Pradesh, Hyderabad
Census of India [37]. www.ap.gov.in

primary and secondary sources of data. Quantitative information was collected using a semi-structured questionnaire and qualitative information was collected through focused group discussions.

This study was carried out in 11 villages coming under C.K. Palli, Ramagiri and Roddam mandals of Anantapur district with least net irrigated area and where organic farming methods are being adopted were selected for the study (Table 4). A total of 120 organic and 120 conventional farmers were selected from the state of Andhra Pradesh from 11 villages using proportionate random technique. Conventional farmers were selected using proportionate random sampling method representing similar dry land conditions except that of their organic farming practices. A thorough review of organic farming policies was conducted through a study of secondary sources. Secondary data on rainfall, net irrigated area and demographic features of the villages were collected from the mandal revenue office and village panchayat records. The study collected data from both primary and secondary sources. Quantitative information was collected using a semi-structured questionnaire during the year 2011–12. Data related to 2009–10 and 2010–11 was also collected using recall method, whereas, qualitative information was collected through focused group discussions. The analysis of the empirical data was basically done by comparing between the various size classes of large, medium and small farmers, and also by comparing between the organic and conventional farmers. The results of the study are discussed at two levels – at the household level and at the plot level.

Table 4 Study area and sampled households in Anantapur district of Andhra Pradesh

Andhra Pradesh –Anantapur district				
	Mandal/		No. of sample households	
S.No	block	Village	Organic farmers	Inorganic farmers
1	Roddam	Rachur	22	21
2	Roddam	Beedanpalli	9	9
3	Roddam	Shapuram	5	5
4	C.K.Palli	Venkatampalli	7	11
5	C.K.Palli	Boocharla	15	15
6	Ramagiri	Kondapuram	13	16
7	Ramagiri	Venkatapuram	5	7
8	Ramagiri	Gantimarri	20	11
9	Ramagiri	Kantiruddi	6	7
10	C.K.Palli	Narsingarayunipalli	9	8
11	Ramagiri	Kuntimaddi	9	10
		Total	**120**	**120**

4 Empirical Results

In this section, an attempt is made to understand the socio-economic profile of the farmers following organic and conventional agriculture. The socio-economic features, age group, literacy level, livestock population, market distance, farming experience, social participation, caste composition, landholding, net income and borrowings are some of the important variables researched in the study. However in this paper the discussion is focused on important variables like size-class, livestock, cropping system, crop and varietal diversity, average agricultural expenditure and economics of ground nut based cropping systems. This analysis is expected not only to provide information about the representativeness of the sample villages, but also to help in getting an insight into the organic farming practices of the sample farmers as against the practices of conventional farmers. Results of the soil sample analysis are also discussed in detail.

4.1 Socio-Economic Profile of the Sample Farmers

The socio-economic features, age group, literacy level, livestock population, market distance, farming experience, social participation, caste composition, landholding, net income and borrowings are some of the important issues focused in this study. This study indicated that most of the organic farming sample farmers were in the age group of 31–40 (31.67%) years, followed by those in 41–50 years (30%), whereas a majority of the conventional farmers were in the age group of 41–50 years (35.83%), followed by 31–40 years (32.5%). In order to understand the social and economic dynamics of

Table 5 Distribution of sampled households according to their size class during 2012–13 (N = 240)

Famer category	Organic farming	Conventional farming
Small farmer (0.1–5 acres)	66 (55.0)	88 (73.33)
Medium farmer (5.1–10 Acers)	38 (31.67)	21 (17.5)
Large farmer (Above 10 Acers)	16 (13.33)	11 (9.17)
Grand total	120 (100.00)	120 (100.00)

Source: Field Survey
Note: Figures in the parenthesis indicate the percentages

sample villages, one has to look into the social system, which largely determines people's perceptions, values and knowledge. Post stratification of the sample households of organic farming revealed that the majority belonged to Backward Classes (38.33%), followed by Scheduled Castes (31.67%). Even among the sample households adopting conventional agriculture, the majority belonged to scheduled caste (37.50%) communities, followed by backward communities (28.33%). Table 5 indicates that the size-class-wise distribution revealed that the majority were small farmers both in case of organic farming (55%) and conventional farming (73.33%). Among the organic farming sample households, only 13.33% belonged to large farmers. Most of the organic farmers belonged to Back ward communities and Scheduled Caste communities and were organized into groups to take up organic farming. Obviously the percentage of small farmers was high in this category.

Among the total sample of conventional farmers, 70% were non-literate, followed by primary educational level (8.33%) and VIII–X (7.5%). Among organic farmers too, the situation was the same, with the majority (60%) being non-literates, followed by primary education (11.67%). Among size classes, in both organic and conventional farming, small farmers had higher social participation followed by medium and large farmers. The reason was due to the thrift of their membership and credit institutions such as Self-Help Groups and occupational-related institutions.

4.2 Livestock

This is the most crucial aspect influencing the soil fertility management practice of both conventional and organic farmers. Both quantity and quality of livestock directly or indirectly influences soil fertility management. Higher the quantity of livestock, more is the access to organic manures. The livestock component of the farming system is crucial to help in maintaining soil fertility, supply of draught power and food for the family [38, 39].

It can be seen from Table 6 that among organic farmers the percentage of bullocks was less with small farmers. Livestock population has reduced because of the fodder and drinking water shortages caused due to recurring drought [40]. Especially,

Table 6 Size-class-wise distribution of sample HHs according to their livestock (per cent)

Livestock category	Conventional				Organic			
	Small	Medium	Large	All	Small	Medium	Large	All
Bullocks (Oxen)	47.00	28.43	41.92	40.27	35.42	39.43	54.54	43.85
Buffaloes	14.50	19.86	13.50	15.80	13.50	11.57	7.10	11.00
Cows	22 .00	20.86	35.25	26.14	26.67	27.00	36.36	30.01
Sheep	9.50	13.71	9.33	10.62	8.16	7.72	2.00	5.25
Goat	7.00	17.14	0.00	7.17	16.25	14.28	0.00	9.89
Grand total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Source: Based on primary survey

bullock population is coming down more with large farmers [4, 41]. The reasons for this are reduction in farm size, increased mechanization, declining area under common lands and changing patterns in labour availability [42]. Another reason is that earlier, children from SC and BC communities worked for the landlords, but they are now going to school due to the awareness created by voluntary organizations and the emphasis given by government on primary education.

Among the sample households of conventional farmers, the majority (40.27%) are seen to have bullocks followed by cows (26.14%), buffaloes (15.80%), sheep (10.62%) and goats (7.17%). In case of organic farming sample HHs, the majority (43.85%) are bullocks. This is slightly (3.58%) higher than conventional farmers.

4.3 Agro-Biodiversity

Farmers of dry land regions developed diversified cropping systems to ensure that the most essential natural resources such as sunlight, wind, rainfall and soil are optimally utilized throughout the year. Crops that were developed over centuries were specifically bred to suit local soils, nutritional needs of people, livestock needs and climatic conditions. A large number of farmers, especially the women have been nurturing the agro-biodiversity and soil fertility without any sort of support from the government [43–45]. The lands of sample farmers of the study villages have hosted a wide range of crops.

Table 7 shows that crop diversity is more in the fields of organic farmers as compared with conventional farmers. The majority (52%) of the sample households adopting organic farming grow at least 5–6 types of crops in the lands owned by them. As much as 44% grow 3–4 crops in organic farms. Diversity provides some protection from adverse price changes in a single commodity and also better seasonal distribution of inputs [4, 46]. In conventional farming, the majority (52%) grow 3–4 crops. Only 1–2 crops are grown by 33.33% of the conventional farmers whereas it is only 2.67% in organic farming.

Table 7 Percentage of total no. of crops grown by sample households in their lands during the year 2011–12 (per cent)

Number of crops	Conventional farming	Organic farming
1–2 crops	33.33	2.67
3–4 crops	52.00	44.00
5–6 crops	14.67	52.00
7–8 crops	0.00	1.33
9–10 crops	0.00	0.00
Total	100.00	100.00

Source: Based on primary survey

4.4 Cropping System

Despite the constant encouragement for monocropping by the agricultural extension agencies and private seed, pesticide and fertilizer companies since the past three decades, farmers still follow intercropping and mixed cropping, as they realizing merits of such cropping system. It is evident from Table 8 that during the years 2009–10, 2010–11 and 2011–12 majority of the sampled farmers were adopting intercropping followed by mixed cropping system. In the case of conventional farming majority were following monocropping followed by intercropping during the years 2010–2011 and 2011–12. However during 2009–10 majority followed intercropping. Farmers value such diversity since it provides greater protection against the risk of crop failure [47]. The reasons given by farmers for crop diversity include access to diverse and nutritive food to the family members, availability of different kinds of fodder to feed the livestock, improvement in soil fertility, and effective utilization of farmland and to make sure that under no conditions of unfavorable environment and climate, the whole crop is lost [43, 48].

By practising inter/mixed cropping, the farmers combine crops with varying lengths of root depth, thus avoiding competition for space, moisture and nutrients. In mixed cropping system, root diversity at different levels below the ground physically stabilises soil structure against erosion and soil movement on steep slopes, and in tropical systems, the contribution of roots to soil organic matter is proportionately larger than from inputs above the ground. The natural process of biological nitrogen fixation by roots constitutes an important source of nitrogen for crop growth. It therefore provides a major alternative to the use of commercial nitrogen fertiliser in agriculture. Intercropping/mixed cropping safeguards against total failure of the crops during unfavourable climatic conditions and can help to increase production and income on dry lands [49].

While in monocropping system, the incidence of pest or spread of disease is easy as there is a single crop, the inter/mixed cropping system itself acts like a barrier to the establishment of pests, thereby reducing the damage. Moreover it becomes difficult for pests to locate food in the mixed cropping system. Interestingly, some of the crops in the mixed cropping system, simultaneously provide food for natural enemies of crop pests.

Table 8 Distribution of sample households according to their cropping system in Kharif 2011–12, 2010–11, 2009–10 in Andhra Pradesh state of India (percent)

Cropping method	2011–12 Organic farming	2011–12 Conventional farming	2010–11 Organic farming	2010–11 Conventional farming	2009–10 Organic farming	2009–10 Conventional farming
Mono crop	7.5 (9)	40.83 (49)	5.0 (6)	40.83 (49)	10.0 (12)	26.67 (32)
Inter crop	42.5 (51)	40.0 (48)	54.17 (65)	42.50 (51)	45.0 (54)	56.67 (68)
Mixed crop	39.17 (47)	18.34 (22)	33.33 (40)	15.83 (19)	44.17 (53)	16.67 (20)
Strip crop	10.84 (13)	0.83 (1)	7.5 (9)	0.83 (1)	0.83 (1)	0.0 (0)
Total	100.0 (120)	100.0 (120)	100.0 (120)	100.0 (120)	100.0 (120)	100.0 (120)

Note: Figures in the bracket indicate actual numbers

4.5 Crop Rotation

Growing of different crops on a piece of land in a pre-planned succession is called crop rotation. Crop rotation ensures that the same soil nutrients are not used up by the crop every season. Crops which use different nutrients are grown alternatively to keep the nutrient balance in the plots. Farmers attach high value to this practice indicating the significant contribution of this practice to soil fertility maintenance since ages. Crop rotation itself does not involve any cost but involves the decision to change the crop every season in a particular plot.

Compared with monoculture cropping practices, multicrop rotations with two or three crops in a year can result in increased soil organic carbon content [50]. This is because of addition of large amount of biomass in the soil, both above as well as under the ground. Such crop planning is practiced in dry land regions. The complexity and diversity of such micro-environments created by farmers are often undervalued [51]. Table 9 clearly reveals that crop rotation is more (53.26%) in organic farming as compared with conventional farming, where crop rotation is followed in only 25.47% of the total sampled plots.

4.6 Per Acre Expenditure and Income

An attempt is made to arrive at the per acre average income of total sample HHs in the year 2011–12. This was calculated by subtracting cost of crop production from gross income of agricultural produce. The analysis was done with respect to groundnut based cropping system.

It is seen from Table 10 that the average per acre agricultural expenditure of the sample households practicing conventional agriculture is Rs. 11,023 and for those

Table 9 Crop rotation in the sampled plots (per cent)

Crop changes	Conventional farming				Organic farming			
	Small	Medium	Large	All	Small	Medium	Large	All
Crop rotation followed	11.43	16.67	40.43	25.47	56.00	55.17	38.46	53.26
Crop rotation not followed	88.57	83.33	59.57	74.52	44.00	44.83	61.54	46.74
Grand total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Source: Based on primary survey

Table 10 Average per acre expenditure (in Rs.) of sample households during the year 2011–12

S. No.	Particulars	Conventional farming	Organic farming
1	Seed quantity	2584	2470
2	Organic fertilizer value	1090	2691
3	Chemical fertilizer	1442	–
4	Bio-pesticide	69	323
5	Pesticide	927	–
6	Human labour	1037	1220
7	Bullock labour	2254	2166
8	Machine labour	1620	1620
	Total	11,023	10,490

Source: Based on primary survey

practicing organic agriculture it is Rs. 10,490. It can be clearly seen that there were no expenses related to pesticide use and chemical fertilizers with organic farming. The expenses on bullock labour were slightly lesser in organic farming. This could be due to the slightly lesser usage of bullocks due to lesser livestock population (especially cows and bullocks) available with organic farmers. The same was revealed by the farmers in the focused group discussions. The expenses on seed were nearly same in both types of farming.

Table 11 reveals that the per acre income is quite less in both organic and conventional farming. The income is almost one-third of the expenditure incurred per acre. This is mainly due to poor yields due to excess rain. During the year 2011–12, it could be seen that income from grain yield was less in the case of organic agriculture as compared with conventional agriculture. Similarly, the per acre income of sample households practicing organic agriculture was Rs. 14,906 which is higher by Rs. 1832 per acre than the conventional agriculture. It was clearly reported by farmers that the yields were slightly higher in organic farms, the input costs were also much lesser in organic farms as compared with conventional agriculture. There is a scope for minimizing the economic cost and environmental loss under organic farming

Table 11 Average per acre Income (in Rs.) of sample households during the year 2011–12

S. No.	Item	Conventional agriculture	Organic agriculture
1	Grain yield	10,182	12,230
2	Fodder yield /stacks/bundles	2290	2276
3	Crop by-products	500	183
4	Uncultivated foods	102	217
	Total	13,074	14,906

Source: Based on primary survey

system as compared to conventional farming in the long run [52]. Based on their 3 years' experience in organic farming, farmers revealed during the FGDs that despite initial lesser yields in organic farms, the per acre net income was equal or more than conventional agriculture due to lesser input costs. This means that organic agriculture is more economically viable as compared to conventional agriculture. However, a series of focused group discussions with several organic farmers in 11study villages clearly brings out the fact that despite a yield reduction of 15–25% in the initial years of shifting to organic farming, lesser input costs in organic farming makes it economically more profitable than conventional agriculture. Some farmers reported during FGDs that the yield in organic farms even in the initial years of shifting from conventional agriculture was no less. It is interesting to notice that the input costs incurred for pest management and fertility enhancement are totally reduced for organic farmers. Though the income from fodder, crop by-products was higher for conventional farmers and uncultivated foods gave higher income in organic agriculture. This could be due to the wider adoption of inter/mixed cropping systems by the organic farmers which resulted in higher availability of uncultivated foods.

5 Organic Farming: Farmer's Perceptions

The present study, in addition to the quantitative data through household interviews, also tried to understand the farmers' perception – especially the women's – regarding the various aspects related to the organic farming. These include reasons for shift to organic farming, yield reduction during conversion, improved health due to organic farming, importance of livestock for organic farming, food habits of the organic farming families, access to uncultivated foods in organic farms, advantages of marketing by women's cooperative, marketing issues involved and advantages of organic farming. In addition to these things, the farmers clearly brought out the impact of organic farming on soil, human beings and livestock.

The farmers who have taken up organic farming were supported by the NGO TIMBAKTU by way of providing various inputs. These initiatives helped the farmers to reduce their inputs costs and also obtain the sustained yields. The major support extended to the farmers by TIMBAKTU include support for collection of cow urine which forms an important input for the preparation of *jeevamrutham*, an organic fertilizer, provided the sprayer, support for taking up soil and moisture conservation works, supply of neem oil, provision of neem cake, provided the seeds of fox tail millet(*Setaria italica*), cow pea(*Vigna catjung*), jowar(Sorghum halepens) and castor (*Ricinus communis*), financial support for crop harvesting, support for marketing organic produce and training through farmers' field school.

5.1 Reasons for Shift to Organic Farming

Organic farmers followed traditional agricultural practices or conventional agricultural practices prior to shifting to organic farming. A combination of reasons encouraged the farmers to shift towards organic farming. The focused group discussions revealed that in chemical farming the input costs have increased and the soils were getting infertile. Due to climatic changes, the crops were not yielding well. At this juncture, the NGO, TIMBAKTU collective created awareness among farmers about organic farming and extended all possible support. The application of chemical fertilizers is spoiling the fertility of the land, crop yields are coming down and health is getting affected. At this juncture the farmers wanted to reduce inputs costs, improve health and get remunerative price for their produce; hence, the farmers quickly accepted the idea of organic farming proposed by TIMBAKTU. Another major reason for shift was that marketing of organic produce was taken care by TIMBAKTU. More importantly weighing of crop produce is done accurately by Dharani Cooperative which comprises of organic farmers as its members. Despite application of more and more chemical fertilizers, the crop yields were not satisfactory and hence, the farmers decided to turn to organic farming hoping that it may increase the crop yields.

5.2 Yield Reduction During Conversion

Regarding the reduction in yields during the conversion from organic to inorganic farming, the farmers during the FGDs expressed that there was not much yield loss for those farmers who had earlier applied good quantities of FYM. For others there was a reduction of 25% yield during the shift to organic farming. When asked how they could cope with this yield loss, the farmers said, "as the input costs have decreased, the net benefits were fine".

5.3 Improved Health Due to Organic Farming

The farmers felt that stoppage of pesticide application had positive impact on their health. Hitherto on the day of pesticide spray to the field, the farmer could never sleep properly due to inhalation while spraying, whereas now with bio-pesticide

Table 12 Impact of organic farming on soil, human health, livestock and neighbouring farmers

On soils
• The soil became smooth; the colour of the soil has changed; the soil, while ploughing, is very loose; the root grub was controlled due to application of neem cake; moisture retention increased from 2–3 days to 6–7 days; manure effect lasts for 2–3 years compared to chemical fertilizers and more earthworms could be seen in organic farms
On human health
• No harmful effects of pesticides; change in food habits: Consumption of more quantities of Jowar and Bajra. Korra rice back into food plate; consumption of good quality cooking oil from Dharani co-operative; earlier body pains were present; less visits to doctor; tasty food and access to uncultivated greens
On livestock
• More variety in fodder; fodder quality improved: earlier they used to sprinkle Gamaxene on fodder to prevent the attack of a bug. Consumption of such fodder resulted in cough to the animal and dysentery. The animal used to be less energetic and always feverish
On neighboring farmers
• Across size-classes farmers were keen to join organic farming groups; started using more organic manures; are using bio-pesticides for pest management; methods of seed treatment with trichoderma, rhizobium and other mixtures is being adopted; borrowing seeds from organic farmers; lesser purchase of chemical fertilizers and adopted higher crop diversity in their farms

Source: Field study

sprays neem seed kernel extract and *Pancha patra kashayam*, there is no such problem. Earlier it was loss of money on pesticides**.** Despite sprays, the crops got damaged and the pests were not controlled. Their health got spoiled and they had problems like itching. Today, even if a bag of neem cake is applied for controlling pests, their health remains unaffected. Earlier the farmers were eating rice purchased in Public Distribution System and it was not doing good for their health, whereas now they consume foxtail millet rice and bread made out of Jowar and Bajra (Pearl millet). They are also consuming different kinds of pulses and uncultivated greens.

Along with the health of human beings, the livestock health too is improved (see Table 12). Fodder from organic farming fields is contributing to the good health of cattle. Earlier, for the *Noomalli* (bug) pest they sprayed gamaxene (BHC) to fodder stacks. Despite the ban BHC is still available. Now due to organic farming practices this is being not done. Due to this the livestock is eating "gamaxene-free fodder" and is keeping healthy. Hitherto, they showed symptoms such as coughing by animals, dysentery, less energetic and feverish.

5.4 Importance of Livestock

Lack of livestock is an important constraint for organic farmers that affected manurial needs and timely agricultural operations. In study village Chinnapalli, more than 50% of the households do not have livestock among the organic farmers. "Livestock is good for organic farming", says, Ramanjaneyulu of Chinnapalli

Village. With own bullocks, farmers can plough the land whenever moisture is available in the land, but if they depend on tractors, they need to give advance to its owner and wait for him to come and plough. By that time moisture in the soil may be lost and seed sowing cannot be taken up. Adding to this, another farmer says, "if the first showers come on time, those who do not own bullocks will face difficulty in ploughing the land". Another point made by the farmers was that the tractor owners have recently increased the per acre ploughing cost from Rs. 450 to Rs. 550, citing the hike in diesel prices.

Some of the farmers in Kondapuram village said that due to lack of bullocks, the land preparation costs went up. Hence, people wanted the financial support for cows and bullocks. Cows give urine whereas bullocks can be used for ploughing. Farmers of Gantimarri, speaking about the importance of livestock for organic farming said, "we face problems in organic farming due to lack of livestock". We need more support for livestock. The multiple benefits provided by livestock include availability of urine, dung, milk, milk products and timely land preparation. The organic farmers revealed during the FGDs that due to korra and jowar cultivation, the fodder availability has increased and hence, more livestock can be maintained with the existing fodder resources. A typical organic farmer with 3 acres of land produces 6 cart loads of groundnut hay +4 cart loads of jowar + half cart load of *korra grass.*

Despite being aware of the value of livestock in farming, the farmers are unable to afford them. Even those who owned livestock had to sell them due to some compulsions, and are now unable to buy them back again as they have to spend huge amount. "If there is no livestock, there is no chance of adding organic manure to our fields", says a farmer.

5.5 Change in Food Habits

With the shift towards organic farming, there is a change in the food habits of many organic farming households, both in terms of type of food and its quantity. In fact, these foods used to find a prominent place in their food basket hitherto. Organic farming families eat *korra* rice at least 4–5 times in a year. Some of the sample households even consume 20–30 times in a year. As compared to hitherto, they are eating more quantities of bajra and jowar. These crops are already being consumed, but now they are eating in more quantities and more frequently. It was revealed by women during the FGDs that the health of the family members of the organic farming households has improved. The indicators expressed by them include that earlier they had body pains, increase in the gap between the visits to doctor; they do not see a doctor even once in 10 days which they used to do earlier, the taste of food grown organically is good and good quality cooking oil is being provided from the Dharani cooperative which keeps us healthy. In study villages like Kondapuram, the farmers are keeping one-third of the total millet crop produced for consumption and the remaining is being sent to the market. Organic farming has increased the access to uncultivated greens in their farms and the frequency of diverse uncultivated greens has also increased among sample hhs.

5.6 Advantages of Marketing by Dharani Cooperative

The major advantage has been the correct weighing procedures adopted by the Dharani cooperative. On the contrary the traders in the open market deceive us. Last year in TIMBAKTU marketing, the price was fixed based on weight; whereas this year, it is fixed as per the general market rate. There is a assured market price for the crop produce. People are in need of money during the weeding stage. As they get financial support from traders, they are forced to sell back the produce to traders and in the process get exploited. In the open market, they lose nearly 8 kg of produce for each bag of groundnut. This is a huge loss. So for each acre on an average the yield is 20 bags which mean 20 × 8 kg = 160 kg, which when valued, comes to almost Rs. 2500–3000. During the groundnut season, if financial support is provided for weeding, the farmers will be relieved of traders, and hence, this 8 kg loss per bag to private traders in market can be avoided. After harvesting, the produce is picked up within a week. Cash is paid quickly, deducting the amount supported for the soil fertility enhancement. Hitherto, the traders used to take 15–30 days for making the payment for the produce sold. Dharani Cooperative farm provides loans for seeds and during harvest. An amount of Rs. 1200 per acre is given to each farmer for purchase of seed. Similarly, Rs. 1000 per acre is given to each farmer for crop harvesting. The loans are given at an interest rate of 1%, whereas if taken outside it will be 5%. The main requirement of the small farmers during the changing times is better access to capital and education [53].

Farmers have brought out an important constraint in marketing of their organic produce. Crops such as red gram have to be picked up quickly as there may be chances of attack by storage pests. Hence, they have to be lifted from farmers immediately and taken to the mills for making *dal*. If taken late, the stored grain is attacked by pests. "After harvesting, red gram must be converted immediately into *dal",* says Pallakka. Those who harvest the pigeon pea first have to wait till the other farmers harvest their produce. But such produce is in the danger of attack from pests during storage and hence needs to be picked up soon. But unless a substantial quantity of pigeon pea is available, Dharani Cooperative will not come to pick up the produce. The produce is picked up only after at least five farmers harvest their produce. As they have so many villages to procure, it is a problem for them too.

6 Conclusion

Organic farmers have been using a range of agricultural practices that are based on local resources. As a result of this the input costs were lesser and more importantly farmers had control over the things they wanted to do. Organic practices related to treatment of seed, soil fertility enhancement, pest management, and livestock care have provided employment to villagers and thereby supported their livelihoods. Based on the empirical evidence it can be concluded that organic farming is economically viable. There was significant reduction in the input costs of organic farms. Each and every single farmer in the study area was appreciative of the marketing support extended to them, especially the accurate weighing procedure adopted by Dharani Cooperative. This enabled them to save an amount ranging between Rs. 2000 and Rs. 3000 per acre, which is a substantial gain for small and marginal farmers. Millets such as korra, jowar and bajra are back into farming system, enhancing the food and nutritional security of sampled households. Huge crop diversity and higher crop rotation was seen in the organic farms as compared with conventional farms. This has positive implications for soil fertility management, pest management and for withstanding risk of climate changes. It was argued by the organic farmers during the FGDs that there is a need for a strong support for livestock, especially bullocks and cows, for better results in organic farming. There is a great scope for the revival of organic farming practices by utilizing the incentives of labour under the National Rural Employment Guarantee (NREG) act [35]. It can be summed up that organic farming is doing better compared to conventional farming on several fronts.

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Index

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