Pesticides and Pests

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Edited by

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TABLE OF CONTENTS

PREFACE

In pursuance of the objectives of the formation of the Society of Pesticide Science, India (SPS India), the Society took upon itself the task of bringing out quality publications on topical themes, of relevance from time to time in the national and international contexts. Over the years, it has published over 25 books, bulletins, monographs and other compilations for the benefit of the scientific fraternity and the public at large. Some of the books published by it such as *Neem Research and Development* (a later revised and enlarged edition of the book was published under the title *Neem*), *Botanical and Biopesticides*, *Minimizing Environmental Hazards of Agrochemicals: Indian Approach and Status* and others won not only high national and international acclaim but also became money spinners for the Society.

The Society's management has now decided to bring out the present publication – *Pesticides and Pests* – to update its readers on fifteen selected topics of relevance in the current context and highlight potential areas of research requiring attention. The topics have been selected keeping in view the research and information needs of the researchers, educationists, administrators, industrialists, public, and others associated with pesticides in one way or another, both in India and elsewhere. These address the realities and challenges of pesticides for food security, the Indian Pesticides Management Bill 2008, the pesticide residue scenario in India in relation to international needs and developments, bio-securing Indian agriculture against exotic insect pests, the impact of climate change and the management options in relation to crop pests, bio-intensive insect pest management, novel agrochemicals to combat the problem of insect resistance, challenges and prospects of herbicide tolerant crops in relation to weed management, environmentally benign pesticides based on essential oils, the role of *Trichoderma* sp. in integrated disease management, the status of multi-pesticide residue analysis, national *vis-à-vis* international developments in quality management in pesticide formulation, advances in mycotoxins detection, the indigenous development of some bio-pesticide formulations, and the role of amendments to mitigate pesticide contamination of soil and water. An effort has been made to introduce the topics comprehensively in the 'Introduction' chapter of the book.

The contributors of the various chapters are renowned and recognized persons in their respective fields. The Society records its gratitude to all the authors for the hard work and painful efforts put in by them. Every possible effort has been made to verify the authenticity of the information. However, the Society or the editors do not own responsibility for the facts and figures reported in the text and the authors alone are responsible for the same.

It is hoped that readers will find the book informative and useful. We apologize for any lapse that may have occurred inadvertently on our part.

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CHAPTER ONE

INTRODUCTION

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Introduction

Based on its performance during the past sixty years or so, India can be proclaimed a winner in the fight between the demand for and supply of agricultural produce. The country registered an all time record harvest of around 272 million metric tonnes of foodgrains during the year 2016-17.[1] This has been possible primarily because of the successful development and adoption of the agricultural inputs and technologies generated indigenously or elsewhere. Nevertheless, there is no room for complacency since the future challenge is tougher, particularly in view of the ever increasing mammalian population, shrinking per capita arable land due to an unending demand for it for non-agricultural uses, the declining farming community and labour force, depleting water resources, an erratic and changing climate, etc. India is expected to become the most populous country in the world by 2022. The food and nutrition outlook of the people is undergoing a sea change with an increasing emphasis on health standards and longevity in life. Over and above this, India is an open economy. All these factors have raised the expectations of the government and the public about agricultural sciences.

Pesticides and agriculture

Agricultural chemicals have attained a centre stage in India's quest for global primacy in agriculture. Being a tropical country, the problem of pests is severe and their management vital. By 2019, the value of the crop protection industry is expected to touch USD 7.5 billion (about INR 47,000 Crore).[2] The rise in exports of chemicals, the growth in production and use of generic products, food quality and safety, increasing productivity per unit of crop area, the growth of horticulture and floriculture, environmental issues, fake products, organic agriculture, biopesticides, changing pest scenario, pest resistance, strengthening R&D setups, biotechnological innovations and the adoption thereof, applications of information technology, etc. are the issues that will hog the limelight in the future. These and other related issues are discussed comprehensively in the chapter “Realities and challenges of pesticides for food security in India”. As the topic is of an ever-evolving nature, the information will require periodic updates. Nevertheless, the scenario to date is discussed.

Pesticide management

The Pesticides Management Bill 2008 was formulated to replace the Insecticides Act 1968 which regulates the manufacture, sale, transport, distribution, export, import and use of pesticides in India. The Central Insecticides Board, a key functionary under the Act, advises the central and state Governments on technical matters and through its Registration Committee approves the use of new pesticides/formulations on crops. The implementation of the regulations is, however, left to the State governments. The Bill was presented in Parliament in October 2008 and then sent to the Standing Committee on Agriculture, which submitted its report in 2009. Parliamentary approval is still pending.

The chapter "The Insecticides Act to the Pesticides Management Bill 2008" provides an overview of the 1968 Act through the times and circumstances that led the Government of India to review it and propose the Pesticides Management Bill. It also provides information on the current national scenario and status on pesticides.

The proposed Bill is already coming under criticism by several bodies for its inability to satisfy the needs of different stakeholders.[3-5] Some of the issues of discord include: allocation of inadequate staff for the implementation of its key provisions, the limited capacity of the government’s 46 pesticide quality control laboratories to handle samples (present capacity is only about 60,000 samples per year), lack of life cycle liability and traceability of the producers and distributors network, price regulation, insufficient provisions to protect human health and the environment, a lack of overall transparency, particularly in data disclosure, etc. Various suggestions made for amending the Bill include: precautionary principle in the objective to give priority to human and environmental health in case of any uncertainty, to prevent the Ministry of Agriculture from acting as Regulator of the Bill since it is a promoter of pesticide use and instead make the Ministry of Environment and Forests or the Ministry of Health the regulator, a comparative risk assessment of the data of old pesticides with the new ones while registering newer products to establish the safety and superiority of the newer introductions, giving powers to States to regulate pesticide use since pesticides may behave differently in different agro-ecological zones, making the manufacturer liable for environmental contamination and human health impacts on the principle of 'polluter pays', the provision of compensation to consumers under the Pesticide Management Bill 2008 rather than the Consumer Protection Act 1986, etc.

Pesticides in food

Ever since the enactment of the Food Safety and Standards Act (FSSA) 2006 and the subsequent Food Safety and Standards Regulations 2010, the onus of fixing permissible limits and ensuring their compliance with respect to food additives, crop contaminants, pesticide residues, residues of veterinary drugs, heavy metals, processing aids, mycotoxins, antibiotics and pharmacologically active substances, and irradiation of food in different food items/commodities has fallen upon the Food Safety and Standards Authority of India (FSSAI). With respect to pesticides and other agrochemicals, the existing maximum residue limits (MRLs) specified under the Prevention of Food Adulteration Act (PFA) 1955 have been incorporated in the new rules.

The monitoring of pesticide residues in food items/commodities, environmental components, etc. in India was conceived during the 1950s. The effort was streamlined and boosted with the establishment of the Division of Agricultural Chemicals at the Indian Agricultural Research Institute (IARI), New Delhi (under the aegis of the Indian Council of Agricultural Research, ICAR) in 1966, and subsequently, based on its research projections, the creation of the ICAR-All India Coordinated Research Project (AICRP) on Pesticide Residues (now named the All India Network Project (AINP) on Pesticide Residues) in 1984 with its headquarters at the Division of Agricultural Chemicals. The project has centres spread all over India and serves as the key component of the national pesticide monitoring programmes by exclusively focusing its attention to various aspects relating to pesticide residues in agricultural crops, food, feed and environmental components. It plays an important role in the establishment of the national pesticide use and safety standards by generating reliable data. Currently, the generation of MRLs has been made a pre-requisite for the registration of a pesticide in India.

The chapter "Pesticide residues in agricultural produce – the scenario in India" highlights national initiatives, efforts and outcomes in enabling the safety of agricultural produce, both for domestic consumption and export. To ensure the credibility of the data being generated, the accreditation of laboratories involved in generating such data has been promoted. 15 laboratories and 25 NABL accredited centres located at different places all over India are currently involved in data generation. Hitherto not available, MRLs and waiting periods for 55 pesticide-crop combinations have been established for reference and use by national and international authorities. Only 2.8% of the vegetable and 1.1% of the fruit samples tested were found to contain residues above the MRL. Out of 113,614 samples analyzed, only 2% revealed pesticide levels above the FSSAI-MRL. The information generated has helped to establish and promote the safety and quality of Indian farm produce as per international requirements, overcoming some of the earlier setbacks the country has received on this account.

Residue monitoring is a continuous exercise. One cannot sit and relax based on one's past laurels and achievements. In the interest of national pride, the quality of agricultural produce has to be authenticated for all the times to come. There cannot be any compromise with meeting the various national and international quality requirements. Therefore, further strengthening this effort by expanding the monitoring network and strengthening infrastructure will only be in the national interest.

Biosecuring Indian agriculture

The Agricultural Biosecurity Bill 2013 aims to establish an integrated national biosecurity system covering plant, animal and marine issues to combat threats of bioterrorism from pests.[6] It is expected to increase the national capacity to protect human health and agricultural production and equip the country in meeting obligations under various trade and sanitary agreements in food and agricultural products. The Bill repeals the Destructive Insects and Pests Act, 1914 and the Livestock Importation Act, 1898. Its parliamentary clearance is pending.

The Bill endows the Agricultural Biosecurity Authority of India with the key functions of regulating the import and export of plants, animals and related products; preventing the introduction of quarantine pests from outside India; and implementing post-entry quarantine measures.

The chapter "Biosecuring Indian agriculture against exotic insects – pests under quarantine umbrella" provides a comprehensive overview on this subject.

The ICAR-National Bureau of Plant Genetic Resources (NBPGR) is the nodal organization to issue import permits, undertake quarantines of plant germplasms including transgenics, and issue phytosanitary certificates for material being exported. During the period 2005-2014, a total of 894,532 exotic germplasm samples of various crops were processed for quarantine clearance, involving the detection of pests and salvaging the contaminated material. A total of 15,715 samples of more than 15 plant genera known to carry hidden infestations of bruchids/chalcids were subjected to soft X-rays, and infestation was detected in 1,430 samples. Intercepted pests were identified. Pest tolerance in quarantine being zero, infested material was salvaged using suitable phytosanitary techniques/treatments such as X-ray radiography (1,430), fumigation (3,269), pesticidal dip/spray (737), etc., and prophylactic treatment was given to ~448,072 samples so as to make the pest-free material available to researchers throughout the country. The success of plant quarantine in biosecuring Indian agriculture was clearly reflected by the interception of a number of exotic pests in the imported plant material, 16 of which are not yet reported from India. These included the bruchids with a wide host range. These were critical as they could become invasive under favourable biotic and abiotic conditions. If not intercepted, these pests could have caused havoc in India.

The Biosecurity Bill has received serious criticism on various accounts, the key ones being:[7] i) it does not include epizootics/zoonoses, disease-causing organisms that can hop from one organism to another, particularly humans (e.g. Avian Flu, Severe Acute Respiratory Syndrome (SARS), Mad Cow Disease, etc., which are transferred from primary hosts to humans); ii) although the Bill does forbid individuals to "possess, move, grow, raise, culture, breed or produce any plant, animal and plant product", it does not clarify how States should act to contain the spread of disease. India's past record in imposing domestic quarantine has been dismal, with numerous diseases that made a localized appearance then spreading all over the country; and iii) the Bill does not provide clear direction on handling emergent situations or on urgent contingent plans. It is hoped that solutions to the various problems will emerge in the course of time.

Climate change and crop pests

Climate change has been recognized as a critical factor affecting the survival of living creatures during the 21st century. The Intergovernmental Panel on Climate Change (IPCC) was set up jointly by the World Meteorological Organization and the United Nations Environment Programme to provide an authoritative international statement of the scientific understanding of climate change. Its periodic statement on the causes, impacts and possible response strategies to climate change are the most comprehensive available. Up-to-date reports are available on the subject that form the standard reference for all concerned with climate change in academia, government and industry worldwide. Its fourth assessment report was published in 2007 in three volumes dealing with the physical science basis, impacts, adaptation and vulnerability, and the mitigation of climate change respectively. The report[8] predicted an increment in temperature from 1.1 to 6.4°C by 2100.

The chapter "Climate change impact on crop pests and management interventions" highlights that global climate change may affect crop yields, the economics of agricultural production, and pest dynamics, including the distribution, phenology and abundance of various species, impacting insect populations directly as well as indirectly through the host plants. Insect responses will be region-specific, though in general, global warming is predicted to intensify the pressure of herbivores on plants. Pest management has the potential to provide eco-friendly sustainable solutions to obnoxious pest problems. However, the effectiveness of the management tactics employed, such as host-plant resistance, bio-pesticides, natural enemies and synthetic chemicals, is liable to be altered by a rise in temperature. It therefore becomes imperative to evaluate the impact of climate change on insect populations and evolve appropriate management adaptations for their effective management. The adaptations could comprise improved pest surveillance, detection of invasive species, reliable pest forewarning techniques, thermo-tolerant sources of host-plant resistance, efficient strains of natural enemies including entomopathogens, enhanced biodiversity in agro-ecosystems and changed pesticide application rates/spray volumes, etc.

General information and forecasts on the likely impact of climate change on the pest scenario[9] and the socio-economic implications of such a change on the farming community are available.[10] Climate change may blunt the impact of current IPM solutions, particularly in light of the climate-enabled development of pest resistance to the management tools. Currently, most of the predictions are based on an extrapolation of conditions and knowledge. However, it is not difficult to simulate the conditions to arrive at reliable predictions and initiate studies to develop management strategies. It would be folly to look for solutions after the problem arrives.

Insect resistance

The Insecticide Resistance Action Committee (IRAC) was formed in 1984 to work as a specialist technical group of Croplife (an industry association) to provide a coordinated industry response to prevent or delay the development of insecticide resistance in insect and mite pests. The committee defined insecticide resistance 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.[10] The pesticide resistance of pests is increasing globally. Nearly 500 to 1,000 species of pests are estimated to have developed resistance to pesticides.[11-12] The subject has received a comprehensive overview.[13-14]

The chapter "Managing insect resistance through efficient use of novel agrochemicals" highlights the global challenge that the problem of insect resistance to insecticides poses to industry, farmers and the scientific community. Resistant insects detoxify, destroy and/or avoid the toxic molecules faster than their susceptible counterparts (metabolic resistance). As a result, several useful pesticides belonging to synthetic pyrethroid, organophosphate, carbamate and organochlorine groups have lost their effectiveness against such insect pests. Several other insecticides of the same or different groups, with similar or different modes of action, have developed cross-resistance or multiple resistances in insect populations. Insect resistance management (IRM), therefore, relies on implementing insecticide use strategies to prolong their effective life spans to contain the resistant populations. From time to time, national and international agencies issue guidelines to overcome/mitigate the menace and thus prolong the effectiveness/commercial lives of insecticides. Some such strategies include periodic monitoring to detect resistance, countering resistance through the use of new molecules with different modes of action, as well as the use of plant incorporated protectants and resistance defeating insecticide synergists. The effective implementation of such programmes requires a well coordinated effort between the developers, producers, users, advisors, regulators and other stakeholders.

Most resistance management packages have only been explored at the researchers' level. Their implementation at the farm level, particularly by farmers with limited or no education and resources, is a stupendous task. Even amongst the advanced countries, it needs to be ascertained whether farmers are able to implement the recommended package of practices conveniently. Quite often, the recommended input is not available at the needed time. The extension agencies need to deliberate upon the possibility of making a success out of the knowledge-based strategies of resistance management that are available for the purpose.

Herbicide tolerant crops

Herbicide resistant (tolerant) crops (HRCs or HTCs) enable the control of multiple weeds through the use of non-selective herbicides. Two herbicide resistant cropping systems are common to soybean, maize, rapeseed and cotton.[15] These are Round Up (a.i. glyphosate) and Liberty Link (a.i. glufosinate). HRCs have been grown commercially since 1984 when the first triazine resistant oilseed rape cultivar (OAC Triton), developed by traditional breeding, was introduced in Canada. Currently, the most cultivated varieties are engineered to tolerate glyphosate though varieties resistant to other herbicides such as 2,4-D; others have also been developed. Monsanto introduced glyphosate resistant soybean in 1996 followed by corn in 1998. About 93% of soybean, 82% of cotton and 85% of corn planted in the USA is engineered for glyphosate resistance,[16] and has resulted in an increased consumption of the herbicide. In addition, it has benefitted farm management, though benefits to consumers are not obvious. It has influenced tillage practices (by encouraging little or no tillage, thus checking soil erosion), the method of herbicide application, control of resistant weeds, improved weed management, and the production of cleaner crops containing fewer non-grain materials.[17-18]

The chapter “Herbicide tolerant crops: challenges and prospects for weed management” highlights the key milestones in the development of these crops and the status of their use. These were first planted in an area of 1.7 million ha in 1996 and occupied 181.5 billion ha in 2014, a record increase of a factor of more than 100. With herbicide tolerance as the dominant trait, the HTCs accounted for nearly 60% of the biotech crops developed, and have impacted weed control in crops like soybean and maize. These ensured the safe use of non-selective herbicides and offered better weed control efficiency by controlling difficult-to-control perennial, herbicide-resistant and parasitic weeds, as well as weeds that are closely related to crops. Their adoption in many crops may reduce the cost of weed management on a short to medium term basis. HTCs should be used as a component of the integrated weed management system (IWMS) along with other methods/options towards the reduction of weed competition below the economic threshold level. The evolution of super weeds, volunteer/self-sown weeds, narrow biodiversity in crop fields, monopoly of manufacturer companies, sudden break of tolerance, food safety, etc. are the concerns that loom large with people. There is a need for more consolidated long-term field experimentation on HTCs to systematically examine the relationship among biotech crops/toxins, soil organisms and soil processes, which will help/hasten the process of the further adoption of these crops globally.

Most of the risks mentioned are based on qualitative estimates, often emphasising the likelihood and severity of anticipated ill effects on human health, the environment and the farming economy. These effects will vary according to the crop, the resistance trait, local weed flora, climatic conditions and farm management practices.[15-20] The risks listed include the development of super weeds (herbicide resistant), changes in the composition of weed flora, the need for other herbicides to control the specific herbicide tolerant weeds, gene flow from resistant crops to other crops or related species causing the development of resistant weed species, pollution effects due to increased herbicide use, diminishing genetic biodiversity of affected species in treated fields (a hazard[21]), and socio-economic risks (illegality of saving seeds, cost of seeds, technology fees, limited suppliers of inputs, property rights of cross pollinated adjacent non-GM crops, threshold levels of GM seeds in harvests from non-GM crops, segregation of GM and non-GM crops in market, pricing of GM and non-GM crops, etc.).

Essential oil/constituent(s)-derived pesticides

Interest in essential oils or their constituent(s)-based/derived pest control materials came to prominence during the last decade of the 20th century, even though aromatic plants have found applications in pest management since ancient times. These plants belong to several families, but Myrtaceae and Lamiaceae are particularly prominent.[22] The oils are a complex mixture of ingredients that act synergistically[23] to influence bioactivity. The safety of most of the materials with regard to mammals and the environment, their low to moderate cost, the fumigant action, their long-term residual non-persistence and the verification of their traditionally claimed traits in the modern format of science are big pluses in their favour. Since several of the materials have already found alternative uses, product quality specifications exist and certain quantities of materials are already available. Pesticidal products based on several of the plants that serve as culinary herbs and spices are exempt from the toxicological data requirement of the Environmental Protection Agency, USA.

The chapter "Environment friendly pesticides based on essential oils and their constituents" highlights the wide spectrum of the bioactivity of these materials, particularly against agriculturally important insect, nematode, weed and plant pathogenic fungi, etc. Insect killing, anti-feedant, oviposition deterrent and growth regulatory activities are primarily due to their repellent, contact and/or fumigant action, attributed to various monoterpenic, sesquiterpenic and related phenolic constituents of the essential oils. For an effective and efficient application, these can be suitably formulated as a liquid or solid, preferably as controlled-release formulations. For a sustained effect, higher application rates and frequent reapplications under field conditions may be required. Owing to the complex mixture of constituents that make up these oils, resistance is less likely to develop in the targeted insect pests. In view of the low persistence and, thus far, absence of reported adverse effects on non-target organisms, essential oils are considered as reduced risk and green pesticides. Owing to their ecologically benign nature, the essential oil based pesticides may become a potential pest control option in integrated pest management (IPM) and in organic agriculture.

Plant-based products for use in agriculture have to be available in sufficient quantities and at a reasonable price. Their cultivation as competitors to foodgrain and other agricultural crops on the limited arable land that is available may not be practical, and their ability to grow in wastelands has not been investigated. Limited crop harvests will lead to the increased cost of the raw material. Their standardization for quality considerations and stabilization to ensure shelf-life compliance will be tough issues. The phytotoxity of essential oils will be another matter of concern. Their selectivity amongst invertebrates and safety for natural enemies also requires an in-depth investigation. Thus a number of issues need to be addressed to enable their fruitful deployment in pest management.

Trichoderma sp. in integrated disease management

Trichoderma sp. are asexual fungi found in all types of agricultural soils, decaying wood, etc. Different strains are recognized for their diverse applications in agriculture,[24-25] including plant disease control, plant growth promotion (root growth, nutrient uptake, etc.), induction of plant resistance against diseases, development of pathogen resistant transgenic plants, degradation of pesticides, cellulosic wastes, and the like.

The chapter "*Trichoderma* species as a bio-agent in integrated disease management for sustainable agriculture" highlights the multifarious role played by the various species of these fungi in agriculture, particularly in disease management. This genus has received a lot of attention as a biocontrol agent due to its survival under harsh climatic conditions, nutrient utilization ability, high reproduction by nutrient utilization and rhizoshere modification, and strong defense mechanisms against plant pathogens resulting in plant growth promotion[26]. The isolates of *T. viride* (IARI P-1; MTCC No. 5369), *T. harzianum* (IARI P-4; MTCC No. 5371) and *T. virens* (IARI P-3; MTCC No. 5370) proved highly effective against several seed- and soil-borne plant pathogens. The novel seed dressing bio-formulation Pusa 5SD and soil applied bio-formulation Pusa Bio-pellet 10G were developed from the potential isolate of *Trichoderma harzianum* (IARI P-4; MTCC No. 5371). The formulations showed long shelf life and remained viable for 2 and 1.5 years respectively when stored at room temperature (25±8°C).

The work presented is no doubt an interesting development. Nevertheless, shelf life at 25°C may not be enough to sustain the product commercially under the predominantly high temperatures prevalent in the different parts of the tropical and sub-tropical climates in India and elsewhere. These register a high of over 45°C during the summers along with high humidity, particularly during monsoons. Therefore, stability needs to be improved further to meet the needs of both the shelf- and field-life.

Multi-pesticide residue analysis

Pesticide residue analysis in food samples has evolved over time. Today, more than 1,000 pesticides are registered for use globally and commodities need to be monitored for the presence of several of these at a given time under different use situations to ensure the safety of consumers. Multi-class, multi-residue protocols[27-30] have been under development/improvement since 1963.

Anastassiades *et al*. (2003)[31] introduced a so-called revolutionary new approach known as QuEChERS (Quick, Easy, Cheap, Effective, Rugged and Safe), involving the single extraction of a small sample (10-15 g) in acetonitrile followed by the addition of salts or buffers to enable the extraction of both the polar and non-polar pesticides, subjecting the extract to dispersive solid phase extraction (d-SPE) to remove residual water and matrix interferences, and a final analysis by GC/MS or LC/MS/MS. The optimization of buffers has led to two widely accepted methods: the CEN

(European Committee for Standardization) Method 15662 using a citrate buffer[32] and the AOAC Official Method 2007.01 using an acetic acid buffer[33]. Being quick, easy and reliable, these have been widely accepted. For added convenience, ready to use and cost-effective tubes (DisQuE dispersive sample preparation kits) are now available, resulting in further simplification and improved reproducibility of the analysis.

The chapter "Multi-residue analysis of pesticides utilizing advanced analytical tools" highlights the developments in analytical tools over the last two decades, especially in the field of chromatography and mass spectrometry, which have facilitated the implementation of highly efficient multi-analyte, multi-class residue analysis methods. On average, these modern technologies have offered a 10-50-fold improvement in the limits of the quantification of the methods, and at least a 10-fold increase in the number of analytes that a single method can target for residue testing in food and environmental matrices. Mass spectrometry (MS) has undoubtedly become the most important technique in modern pesticide residue testing laboratories. The implementation of gas chromatography-mass spectrometry (GC-MS) with several technological advancements including the utilization of selective reaction monitoring transitions, product ion library, etc. allow a targeted screening of pesticide residues with high sensitivity and reproducibility. Further, there are possibilities of non-target screening at unit and high mass resolution using GC (xGC)-ToFMS and GC-QToFMS. The second revolution came with the introduction of liquid chromatography-mass spectrometry (LC-MS), which opened the door to the analysis of more polar pesticides that were previously difficult to analyze, especially in a multi-residue situation. The advancements in the speed and sensitivity of modern GC-MS and LC-MS instruments allow the analysis of hundreds of pesticides at very low levels in one analytical run. The latest developments in the screening methods based on high resolution mass spectrometry, together with associated developments in micro-flow devices, ion mobility, ambient ionization, etc. have led to a precision in the analysis.

Comprehensive food safety assessment requires multi-residue analysis that involves the identification and quantification of the residues of a large number of compounds with diverse chemistries in a sample by a single method. A typical workflow for multi-residue analysis comprises sample pre-processing, extraction, cleanup and finally injection into the analytical instrument for a qualitative identification and quantitative estimation of the pesticide residues. Screening of pesticide residues involves three approaches, namely reliable target-oriented screening when certified reference standards are available to support compound identification and accurate quantification, screening for suspected analytes when a certified reference standard is not available, and screening for unknowns based on high resolution mass spectrometry.

The scientific quest for innovation and improvement has revolutionized the pesticide multi-residue analysis and will continue to inspire and drive researchers for further novel developments. One only has to wait and watch the direction this research will take in the future.

Pesticide formulation quality

Pesticide formulation quality is governed by factors such as the quality of the active ingredient, formulants and other auxiliaries employed; the preparation, storage and the use environment; the type of formulation, etc. The reformulation of shelf expired materials, the introduction of fake or misbranded products in the market, the false declaration of contents, etc. further aggravate the problem.

Free international trade has brought the subject of pesticide formulation quality to the fore. Each formulation is generally governed by two sets of quality specifications in a country, the one for domestic use and the other for international trade. In most instances, the international requirements are not only more stringent but the products also have to undergo tougher scrutiny. It is therefore appropriate that proper quality control and quality assurance systems are put in place. Extensive information on quality related aspects is available.[34-38]

The chapter "Pesticide formulations: International specifications and test methods" provides an overview on the topic. India has been a signatory of the Mutually Acceptance Data (MAD) agreement of the member countries of the Organization for Economic Co-operation and Development (OECD) since 2011, according to which it is the responsibility of all manufacturers to maintain the quality of agrochemicals produced as per the requirements of international standards and specifications. The main purpose of the agreement is to lift trade barriers and provide a conducive environment for exports. This helps to avoid the rejection of an exported product by the importing country. Even though country-specific standards are set to meet national needs through simplified procedures, most of these specifications differ from the global standards as prescribed by the FAO/WHO. In India, the Bureau of Indian Standards prescribes specifications and test methods for different technical and formulated pesticide products.

In view of the limitations in developing newer molecules, pesticide formulation is considered a potential domain for the future. Several new formulations have already arrived on the pesticide scene during the past three to four decades. These are considered environmentally benign, though its comparative advantage *vis-à-vis* traditional formulations has hardly been worked out. It would be highly appropriate to streamline and strengthen this area in future.

Mycotoxins detection

Mycotoxins are toxic substances produced by moulds (fungi). Toxigenic fungi are everywhere in nature and can infest and contaminate agricultural products under suitable hot and humid conditions. *Aspergillus*, *Fusarium* and *Penicillium* are commonly associated with foods. Amongst the thousands of mycotoxins that exist, the most prominent are aflatoxins, deoxynivalenol (DON), zearalenone (ZEA), ochratoxin, fumonisin and patulin.[39] Methods for their detection/analysis based on chromatography, immunology, fluorescence polarization immunoassays, molecularly imprinted polymers, infrared spectroscopy, capillary electrophoresis, surface plasmon resonance biosensors, etc. are reported.[40-42]

The chapter "Advances in mycotoxin detection" reports the advances in nanotechnology and their impact on developing ultrasensitive devices. A variety of nano-structured materials have been used for the development of immunosensors for mycotoxin detection, which provide an effective quality control system to identify mycotoxin-contaminated food or agricultural produce. Most of the literature addresses ochratoxin A (OTA) and aflatoxin B1 (AFB1) detection in food samples. The article creates a general awareness about the mycotoxins and their detection using nano-structured materials and biosensor technique.

Public awareness on mycotoxins is necessary as most people are ignorant about their potential danger.

Biopesticide formulations

There are two significant definitions of biopesticides, the one given by the European Union (EU) and the other by the US Environmental Protection Agency (US EPA). The former describes biopesticides as "a form of pesticide based on micro-organisms or natural products" and the latter as "naturally occurring substances that control pests (biochemical pesticides), microorganisms that control pests (microbial pesticides), and pesticidal substances produced by plants containing added genetic material (plant incorporated materials or PIPs)". Biopesticide formulations may be based on microorganisms such as bacteria, viruses, fungi, nematodes or others *per se* or the plant part(s) or the active ingredient(s) from microorganisms or plants including plant extracts and semio-chemicals. These are formulated both as solids as well as liquids, exemplified respectively by Dustable Powder (DP), Granule (GR), Seed Dressing (DS), Water Dispersible Powder (WP), Water Dispersible Granule (WG), Slow or Controlled Release Polymeric Product (CR formulations), etc., and Solution (SL), Emulsifiable Concentrate (EC), Emulsion, oil in water, Concentrate (EW), Suspension Concentrate (SC), Oil Dispersion (OD), Capsule Suspension (CS), Suspo-Emulsion (SE), Low or Ultra Low Volume Sprays (LV or ULV), etc. The key objectives of the formulation of biopesticides remain improved storage (shelf-life), application, handling and performance. Detailed information on the topic is available.[43-45]

The chapter "Some biopesticide formulations developed at IPFT" reports promising biopesticidal formulations developed at the Institute of Pesticide Formulation Technology (IPFT), Gurugram, Haryana, India. The described products are mostly based on plant materials and are effective against household and storage pests. These possess good shelf-life and are economical and biodegradable.

Biopesticides are projected as products of the future. Several multinational companies have come in a big way to promote this ecofriendly pest control option. Following the European Union's 2009 'Sustainable Use Directive' on pesticides to reduce the risks posed to human health and the environment, Europe is set to overtake America to become the biggest market in the world for non-chemical pesticides. At present, 91 bio- and agrochemical firms are manufacturing biopesticide products in Europe and 35 products are available in the UK; in the UK alone, however, the biopesticide market is booming with an annual growth rate of 15%, compared to 3% for synthetic products.[46] These developments highlight the need for a better preparedness to meet future needs.

Soil amendments and pesticide behaviour

The organic matter content plays an important role in influencing the sorption, transformation and transport of pesticides in soils. The effect is through an influence on microbial activity, total organic matter, dissolved organic matter, etc. Diverse changes in pesticide behaviour have been reported depending upon the nature and type of soil and organic matter, the physico-chemical properties of pesticides and soils, the nature of the transformation products, etc. The subject has great relevance in the context of environmental pollution and protection and mammalian health, and has received worldwide attention.[47-49]

The chapter "Effect of soil amendments on pesticide adsorption and leaching" highlights the interplay of physical, chemical and biological forces that act upon a pesticide in a complex and dynamic soil system. It provides an overview of the basic and applied concepts, which enables an interpretation of the interactions and the consequences thereof. Leaching is of great importance as it leads to the migration of pesticides to lower soil profiles and may cause ground water pollution. Sorption is the key phenomenon which significantly affects the pesticide leaching behaviour by determining the ratio between the amount of pesticide found in the liquid and solid phases, and allows an assessment of the potential risks associated with the exposure to the retained and dissolved/suspended pesticide. Soil amendments can play a crucial role in the management of runoff and leaching losses of pesticides as they change the physico-chemical properties of soil, which in turn, affect the sorption and transport of the soil-applied pesticides.

The subject is of vital importance in understanding the distribution of xenobiotics in soils.

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CHAPTER TWO

REALITIES AND CHALLENGES OF PESTICIDES FOR FOOD SECURITY IN INDIA

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"The Discovery of Agriculture was the first big step toward a civilized life"
—*Arthur Keith*

Introduction

Agriculture is one of the most basic means of human survival. It is not solely based on food, but encompasses a way of life, because it helps to provide food, clothing (fiber) and shelter.

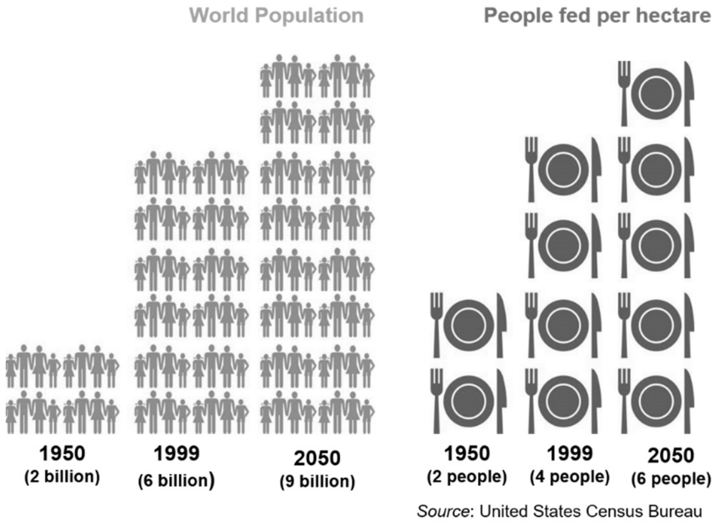

Figure 1. Rising world population and people fed per hectare

The world's population increased from 2 billion in 1950 to 6 billion in 1999, and is slated to touch over 9 billion by 2050.[1] A population increase of this magnitude will place greater pressure on the world's available resources like water and land. In addition, one of the leading concerns in the world today is food security. In the next four decades, nearly 1 billion people will suffer from hunger and malnutrition. The number of human beings fed per hectare of agricultural land is estimated to increase from 4 people in 1999 to 6 people by 2050 (Fig. 1). These factors will require an increase in global food production by about 70% by 2050 in order to meet the rising demand. There is a pressing need for human kind to work towards achieving this goal of ensuring food and nutritional security for the burgeoning population.

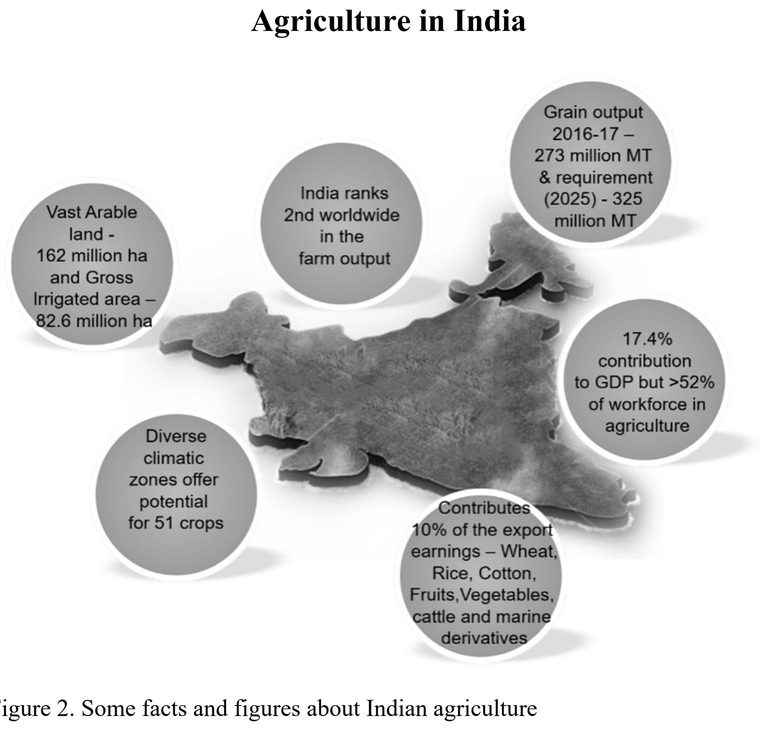

Figure 2. Some facts and figures about Indian agriculture

Agriculture plays a vital role in India's economy (Fig. 2). Over 52% of the workforce depends on agriculture as the principal means of livelihood. As per estimates by the Central Statistics Office (CSO), agriculture contributes 14% to the gross domestic product (GDP) of the country.[2]