Pesticide Residues:

Concerns, Regulations and Management

Chandrakant G. Sawant

In recent years, farmers have faced many challenges such as global warming, attack of insect pests, the fraudulence of pesticides, pesticide residues in food, etc. Policymakers, scientists, extension personnel, etc, were constantly taking emphasis to solve problems related to new technology, update of the technology, technology transfer, scientific training, crop production, and its marketing, etc. Nowadays, consumers are showing an increased interest in organic foods due to the detrimental health effects of chemicals used while cultivating soil and food production. Therefore, it is a need of an hour to work on a risk-benefit analysis of pesticides before using any types of pesticides. The book entitled "Pesticide Residues-Concerns, Regulations and Management" discusses the effects of pesticides on the environment and agriculture, types and modes of action of pesticides, management of pesticides, sources of pesticide residues, and different analytical methods of pesticides detection in fruits and vegetables, bioassay of pesticides, label claim, laws and regulations over the pesticides use, guidelines of codex alimentarius commission. In addition to this, methods of pesticide residue reductions in fruits and vegetables, alternatives of pesticides, and the prospectus of organic farming in India are also discussed.

The readers of this edited book will be the undergraduate and graduate students, researchers, academics, and workers working in different aspects of food production in agriculture. In addition, professionals working in the food industry and regulatory authorities will find this book informative and fruitful. I am confident that the readers will find this book informative and enlightening.

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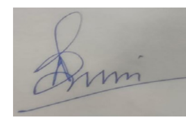
FOREWORD

Agriculture is the primary source of livelihood for about 58 percent of India's population. After independence, the country has made immense progress toward food security. India's population has increased by threefold, whereas our food grain production has increased by four times, with current production at 310 million metric tones. A substantial increase in available food grain per capita has been achieved. Production of food grains has been increasing every year, and India is among the top producers of several crops such as wheat, rice, pulses, sugarcane, and cotton. It is the highest producer of milk and the second highest producer of fruits and vegetables. With the adoption of intensive agricultural practices, agricultural production continues to be affected by biotic and abiotic factors. However, biotic factors (i.e., insect pests, diseases, weeds, nematodes, and other arthropods) are of serious nature. The pests cause considerable damage. Annual production losses in India are reported to the tune of US $12.02 billion despite the use of 60,000 MT of pesticides. As per another estimate ₹ 90,000 crores worth of crops is lost annually due to pests in India.

Industrialization of agriculture has led to the use of large quantities of agrochemicals. More than 2,17,000 MT of technical material was produced in India during 2018-19. There are 1175 pesticide molecules with chemical and biological origin around the world. India is not only self-sufficient in pesticides but exports significant quantities to other countries. Our country occupies the fourth position as a producer of pesticides globally with a pesticide market worth ₹214 billion in 2019, which is projected to grow to a level of ₹ 316 billion in 2024. According to FAO, India's average use of pesticides is less than 0.5 kg/ha, whereas China uses 13. 06 kg/ha, Japan (11.85 kg/ha,) and Brazil (4.57 kg/ha). Although we use less quantity of pesticides, only eight states in India use more than 70 percent of the total quantity. 292 pesticides are registered for use in India; 104 of them have already been banned in one or two countries. The impact of pesticide use on soil and the environment and the presence of pesticide residues in food products is a matter of concern. Non-judicious use could pose a potential threat to humans and other forms of life. Therefore, creating awareness about unwanted side effects on human health and the environment becomes necessary to derive maximum benefits from pesticide use in agriculture. Dr. C.G. Sawant and his team has done commendable efforts by compiling information from different sources in this book. I am sure it will provide critical information on this subject to the students, teachers, researchers, and field workers working on these lines.



S. N. Puri

Preface

An increase in food production is the foremost goal of all the countries in the world, as the world population is continuously growing at a constant rate to reach about 10 billion by 2050. As a result, the world population is constantly increasing by an estimation of 97 million per year. An alerting forecast issued by the Food and Agricultural Organization (FAO) of the United Nations that world food production needs to be increased by 70 percent to meet the demand of the growing population all over the world. The use of pesticides has increased because of the increasing demand for agricultural crops and decreasing availability of farming lands. Pesticides are widely used in agriculture to manage and eradicate insect pests, weeds, and diseases. While cultivating the soil and increasing crop production to meet the emerging demand of the growing population, herbicides, insecticides, fungicides, nematicides, fertilizers, and soil amendments are now being used unwisely and indiscriminately than in the past. These pesticides and their residues are often persistent; they contaminate the terrestrial and aquatic biodiversity, posing a long-term threat of entering directly and indirectly into the human body via the food chain. Apart from this, most of the non-degradable pesticide residues have also entered into the food chain and food web of humans and wild animals and have bioaccumulated in the higher tropic level. In addition, toxicologists and environmentalists 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 infections, and reproductive development effects. In addition, consumers and different environmental groups have enormously prominent on managing and monitoring pesticide residues in foods at various stages.

Fruits and vegetables have played an important role in human nutrition and health since ancient times; they constitute an important part of our daily diet. They are an important source of many sources like carbohydrates, vitamins, trace minerals, and antioxidants. Indiscriminate use of pesticides to manage and control the different insect pests in fruits and vegetables can lead to pesticide residues beyond the MRLs set by international, national, and local authorities. For example, if the farmers were to follow good agricultural practices (GAP), pesticide residues may be below the maximum residue limit (MRL). In general, reports of many studies and investigations carried out by researchers across the world clearly indicated that pesticide residues are present in most fruits and vegetables, whether they may be below MRL or above MRL.

In recent years, farmers have faced many challenges such as global warming, attack of insect pests, the fraudulence of pesticides, pesticide residues in food, etc. Policymakers, scientists, extension personnel, etc, were constantly taking emphasis to solve problems related to new technology, update of the technology, technology transfer, scientific training, crop production, and its marketing, etc. Now a day, consumers are showing an increased interest in organic foods due to the detrimental health effects of chemicals used while cultivating soil and food production. Therefore, it is a need of an hour to work on a risk-benefit analysis of pesticides before using any types of pesticides. The book entitled "Pesticide Residues in Fruits and Vegetables; Health, Regulations and its Management" discusses the effects of pesticides on the environment and agriculture, sources of pesticide residues, different types, modes of action, analytical methods of pesticides detection in fruits and vegetables and laws and regulations over the pesticides use. In addition to this, methods of pesticide residue reductions in fruits and vegetables, alternatives of pesticides, and the prospectus of organic farming in India are also discussed.

The readers of this edited book will be the undergraduate and graduate students, researchers, academics, and workers working in different aspects of food production in agriculture. In addition, professionals working in the food industry and regulatory authorities will find this book informative fruitful. I am confident that the readers will find this book informative and enlightening.

Chandrakant G. Sawant

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Dr. C. G. Sawant is born on 24^{th} October, 1990 at Kauthali, Tal. Parali Vaijnath, Dist. Beed (Maharashtra). He is presently working as an Assistant Professor (Plant Protection) in Multi Technology Testing Centre & Vocational Training Centre, Selesih, Aizawl and College of Horticulture, Thenzawl (Mizoram) under Central Agricultural University, Imphal (Manipur). He has more than 3 years of teaching and research experience in the field of Agricultural Entomology. He has pursued his B.Sc. (Agriculture) and M.Sc. Agri (Agricultural Entomology) Degree from Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani (Maharashtra). He has pursued his Ph.D. degree in Agriculture (Agricultural Entomology) from Mahatma Phule Krishi Vidyapeeth, Rahuri (Maharashtra). He has qualified ASRB-NET two times in Agricultural Entomology.

Dr. C.G. Sawant has awarded "Certificate of Merit" and "Late Gopal Kishan Kale Prize" for securing first rank during Post Graduation. He has also awarded with "INSPIRE FELLOWSHIP" for Doctorial Research by Department of Science and Technology, Ministry of science and Technology, GOI, New Delhi. He has Awarded with "BEST DOCTORAL THESIS" by Society of Science and Technology for Integrated Rural Improvement, Thorrur, Warangal, (Telengana), India. He also awarded with "BEST RESEARCH SCHOLAR" and "CERTIFICATE OF EXCELLENCE" by Professional societies.

Dr. C.G. Sawant has published 22 full length research papers in various National, International and NASS rated journals, 12 abstract, 1 book, and above 30 popular and review articles in Marathi and English Agricultural magazines. He has delivered and broadcasted 2 radio talks on All India Radio Station (Akashwani). He is the life time member of six professional societies related to Agriculture and allied sector.

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Chapter - 1

Introduction and Scenario of Fruits and Vegetables Production in India

B. Vanlalneihi, S. Phibahunjai Syiem, Lalhmingsanga,
Chhungpuii Khawlhring, B. Lalramhlimi and C.G.Sawant

Introduction

High concentrations of dietary fiber, vitamins, minerals, phytochemicals, especially antioxidants, present in fruit and vegetable crops make them excellent sources and are therefore considered in dietary guidance (Dhandevi and Rajesh, 2015). The general recommendation for intake of fruit crops is 400 grams/day and for vegetable crops is 300grams /day, which includes green vegetables and root and tubers of 50 grams/ day each and other vegetables 200 grams/day (Sachdeva *et al*. 2013).

After China, India has the largest area and production in fruit and vegetable crops. Horticulture production has shown an increasing trend over the years and as per the 3rd advance estimate 2020-21, total Horticulture production is 331.05 Million tonnes as compared to 2017-18 which was 310.67 Million metric tonnes as depicted in the graph (Figure 1.1).

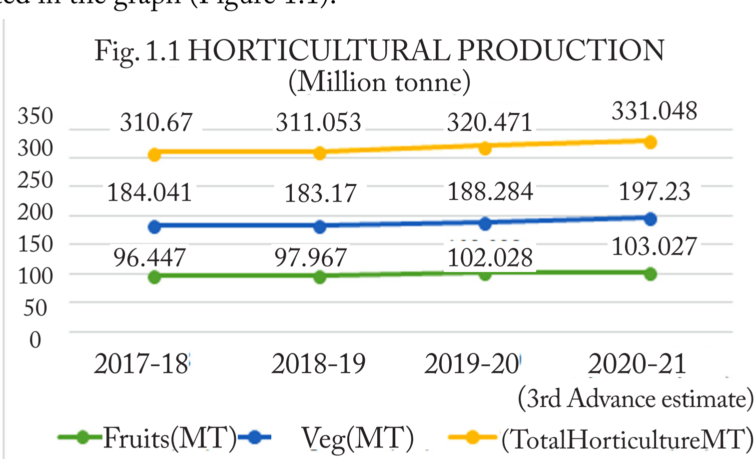


Table 1. The scenario of horticulture area, production, and productivity in India

Particulars	Area (M ha)	Area share (%)	Production (MMT)	Production share (%)	Productivity (MT/ha)
Fruits (including nuts)	6.914	25.06	103.027	31.12	14.90
Vegetables	10.966	39.75	197.23	59.58	17.99
Spices	4.528	16.41	10.679	31.12	2.36
Flowers	0.329	1.19	2.605	0.79	7.92
Aromatic and medicinal crops	0.659	2.39	0.779	0.24	1.18
Honey			0.125		
Plantation crops	4.19	15.19	16.602	5.01	3.96
Total	27.586	---	331.048	---	12.00
M ha- Million hectare, MMT- Million Metric Tonne, MT- Metric Tonne, ha- hectare (3rd Adv. Est. 2020-21).					

Among the horticultural produce, vegetable crops occupy the largest area and production, 10.97 Million hectares and 197.23 Million tonnes, respectively. This showed a significant increase in production from 2017-18, which was 184.041 Million Tonnes. It is followed by fruit crops with showed an increase from 96.45 million tonnes (2017-18) to a production of 103.03 Million tonnes from an area of 6.914 Million hectares (3rd Adv. Est. 2020-21). In India, Karnataka ranks first in area (2362.84 Thousand hectares) and Uttar Pradesh in production (37582.42 Thousand tonnes) of Horticultural crops. Uttar Pradesh has the second largest area of 2282.40 thousand hectares, and West Bengal has the second largest production of 32681.17 Thousand Tonnes (3rd Adv. Est. 2019-20).

Fruit Crops

In India, the largest area in Fruit crops is occupied by Mango (2.33 Million hectares) followed by Citrus (1.09 Million hectares) and Banana (0.92 Million hectares). In contrast, Banana leads in production (33.38 Million tonnes) followed by Mango (20.82 Million tonnes) and Citrus (14.26 Million tonnes) with the highest productivity in Papaya (40.42 MT/ha) and followed by Banana (36.16 MT/ha) shown in figure 1.2, 1.3, 1.4.

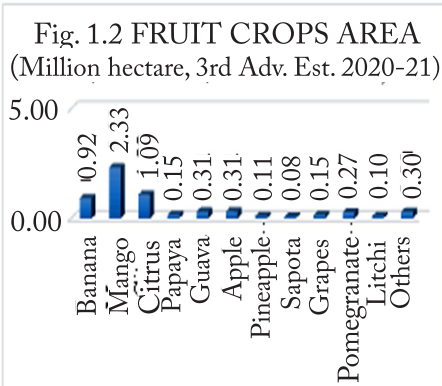


Fig. 1.2 FRUIT CROPS AREA (Million hectare, 3rd Adv. Est. 2020-21)

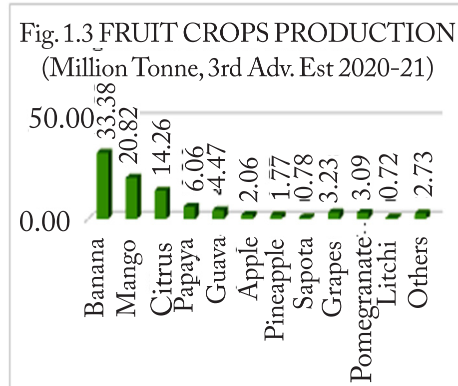


Fig. 1.3 FRUIT CROPS PRODUCTION (Million Tonne, 3rd Adv. Est 2020-21)

Maharashtra has the largest area (785.13 Thousand hectares) and is the second largest in production (11544.26 Thousand tonnes). Andhra Pradesh has the largest production (17515.92 Thousand tonnes) and second largest in area (708.49 Thousand hectares) figure 1.5, 1.6. In India, Karnataka has the highest area (110.55 Thousand hectares) in Banana, and Andhra Pradesh has the highest in production (50003.07 thousand metric tonnes). In Mango, Uttar Pradesh has the largest area (265.62 Thousand hectares) and production (4551.83 Thousand metric tonnes) (NHB, 2018).

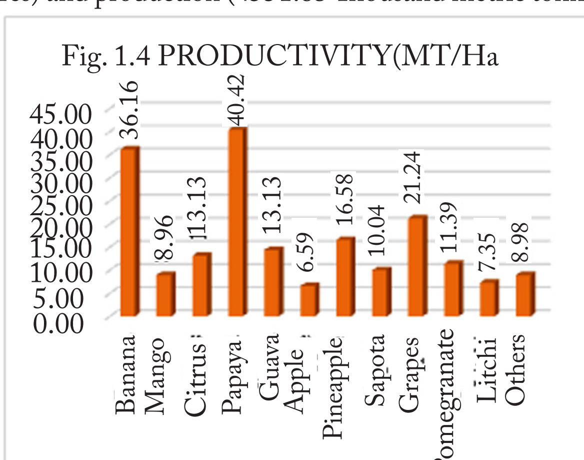


Fig. 1.4 PRODUCTIVITY(MT/Ha

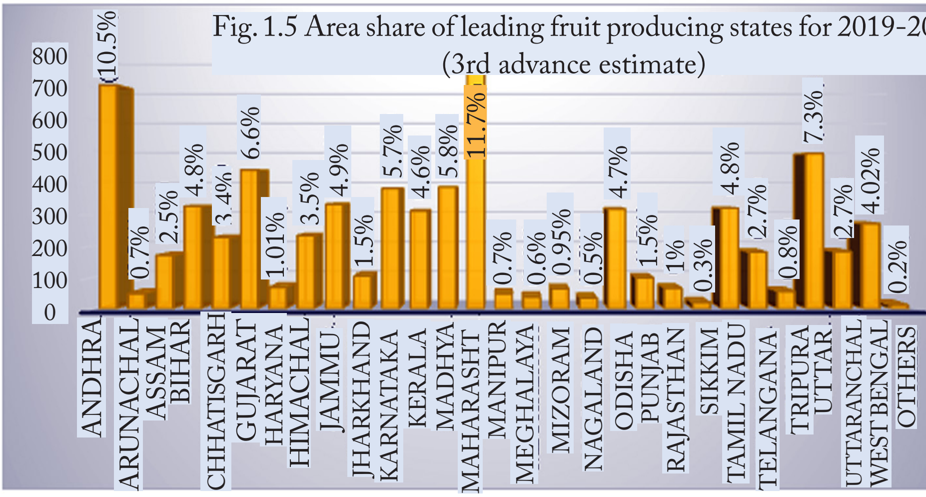


Fig. 1.5 Area share of leading fruit producing states for 2019-20 (3rd advance estimate)

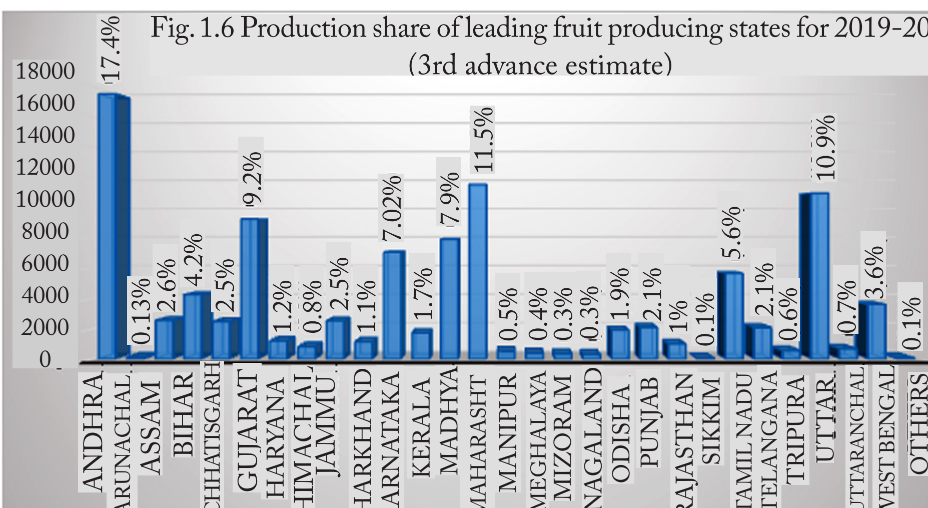


Fig. 1.6 Production share of leading fruit producing states for 2019-20 (3rd advance estimate)

Vegetable Crops

The largest area (2.248 Million hectares) and production (54.23 million tonne) in vegetable crops in India is occupied by Potato, followed by Onion, in addition, Tapioca has the highest productivity (Figure 1.7, 1.8, 1.9). West Bengal begs the largest area and production in vegetable crops with 1501.07 Thousand hectares and 28113.03 Thousand tonnes, respectively, followed by Uttar Pradesh (26194.61 Thousand tonnes). Andhra Pradesh has the highest productivity in Vegetable Crops (Figure 1.10, 1.11). Uttar Pradesh ranks first in the area (614.78 Thousand hectares) and production (15555.53 Thousand tonnes) of Potato while Madhya Pradesh in Productivity. In Onion, Maharashtra leads in the area (507.96 Thousand hectares) and production

(8854.09 Thousand tonnes) and Gujarat in Productivity. Odisha leads in the area (91.01 Thousand hectares), and Andhra Pradesh leads in the production of Tomato (2744.32 Thousand metric tonnes) and highest productivity by Madhya Pradesh (NHB, 2018).

Fig. 1.7 Vegetable Crops Area (Million hectare, 3rd Adv. Est. 2020-21)

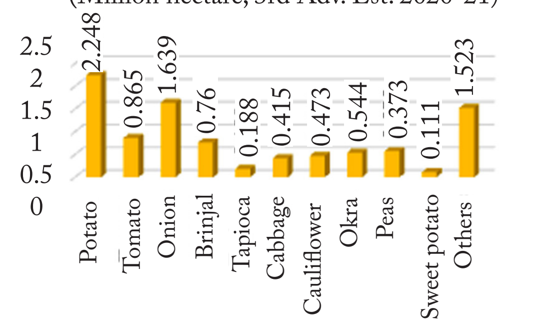


Fig. 1.8 Vegetable Crops Production (Million Tonne, 3rd Adv. Est 2020-21)

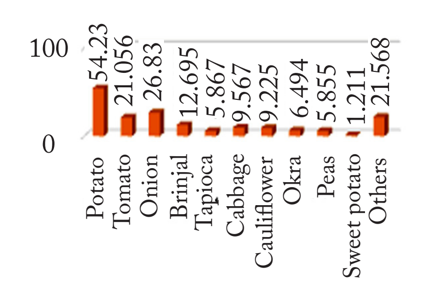
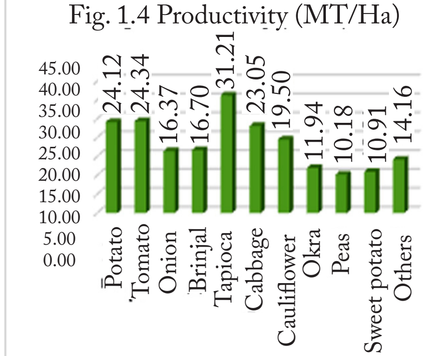


Fig. 1.4 Productivity (MT/Ha)



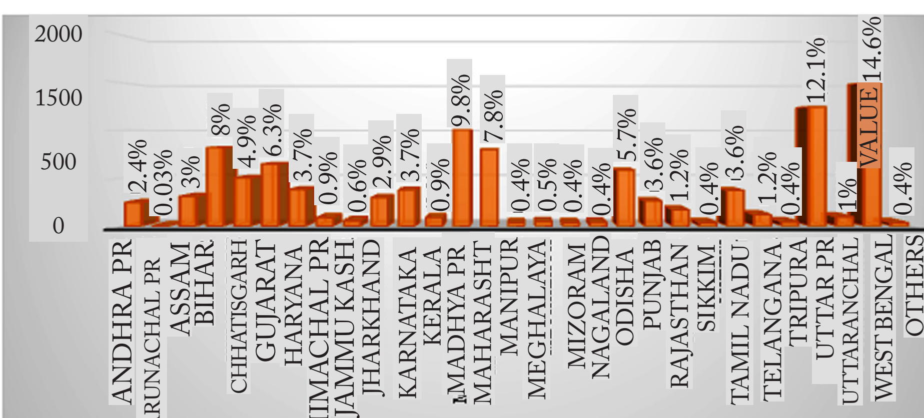


Fig. 1.10 Area share of leading vegetable producing states for 2019-20 (3rd advance estimate)

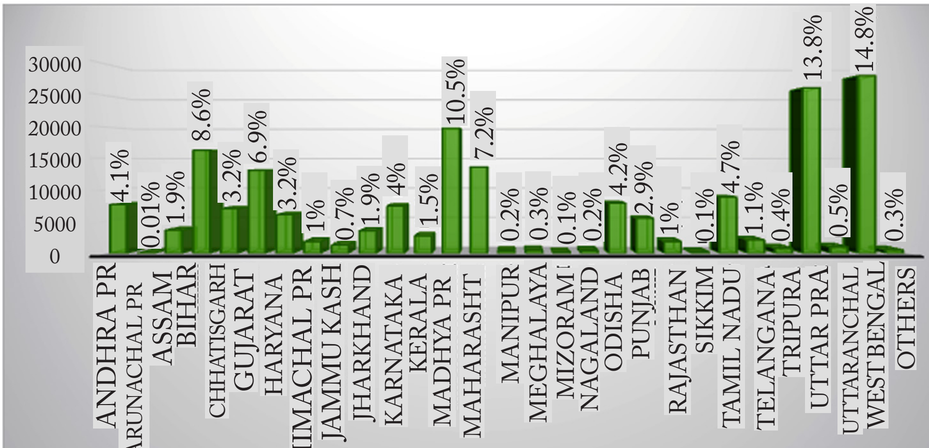


Fig. 1.11 Production share of leading vegetable producing states for 2019-20 (3rd advance estimate)

Spice Crops

In Spice Crops, Rajasthan leads in the area (873.27 Thousand hectares) followed by Gujarat (382.72 Thousand hectares). The spice production is top by Rajasthan (3010.17 Thousand tonnes), with Uttarakhand having the highest productivity (5.88 MT/ha) as shown in Figure 1.14, 1.15. Among spice crops, cumin holds the largest in the area (1.241 Million hectares), with the largest in production was occupied by garlic (3.185 Million Metric tonnes) as shown in Figure 1.12, 1.13. Gujarat and Rajasthan are the highest cumin producer, with an annual production of 384.47 Thousand tonnes and 302.17 Thousand tonnes, respectively. In Garlic, Rajasthan holds the largest area and production, which is 112.89 Thousand hectares and 582.08 Thousand tonnes (NHB, 2018).

Fig. 1.12 PRODUCTIVITY(MT/Ha)

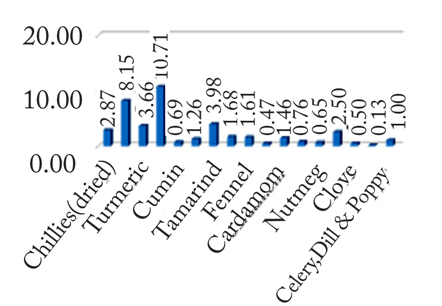
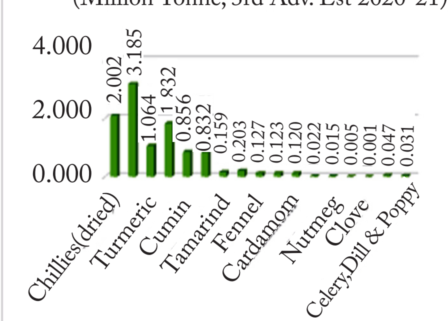


Fig. 1.13 SPICE CROPS PRODUCTION (Million Tonne, 3rd Adv. Est 2020-21)



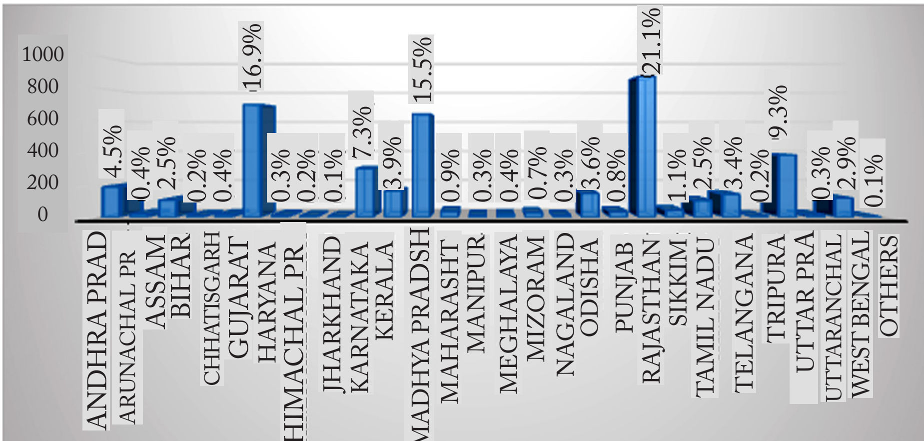


Fig. 1.14 Area share of leading spice producing states for 2019-20(3rd advance estimate)

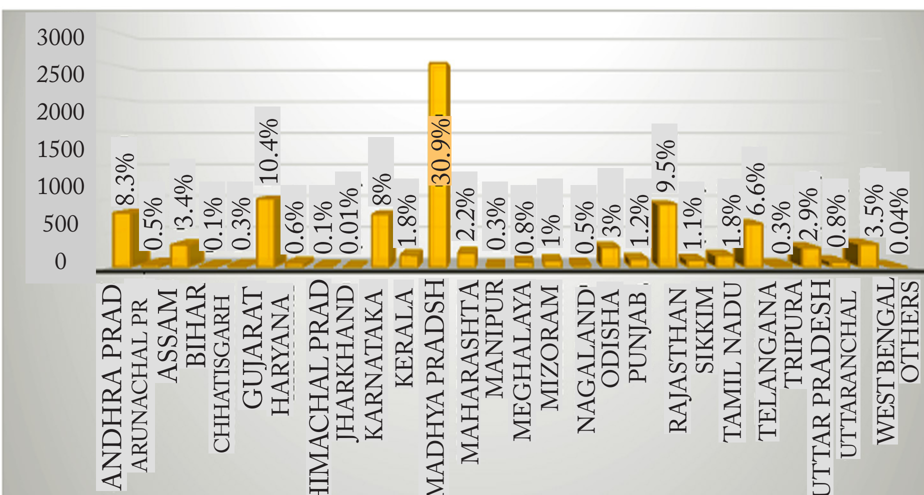


Fig. 1.15 Production share of leading spice producing states for 2019-20(3rd advance estimate)

Plantation Crops

In Plantation crops, Coconut occupies the largest area (2.185 Million hectares), production (14.572 Million tonnes,) and productivity (6.67 MT/ha) in India followed by cashew nut in area (1.159 Million hectares) and arecanut in production (1.265 Million tonnes). Kerala holds the largest area (971.59 Thousand hectares) and production (5505.84 Thousand Tonnes) and productivity (5.67 MT/ha) in Plantation crops. (Figure 1.16, 1.17 and 1.18).

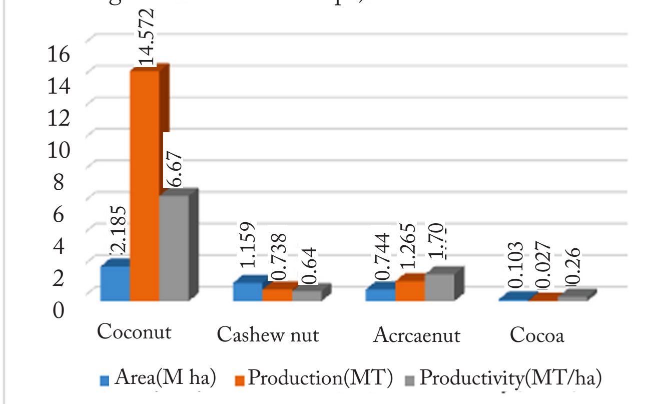


Fig 1.16 Plantation crops, 3rd Adv. Est. 2020-21

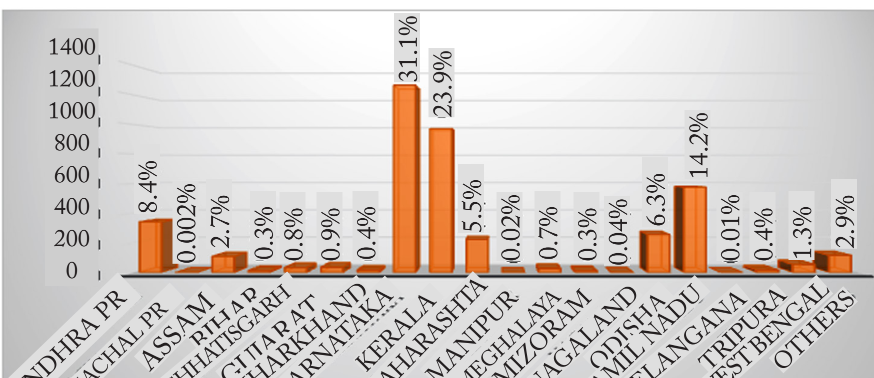


Fig.1.17 Area share of leading plantation producing states for 2019-20 (3rd advance estimate)

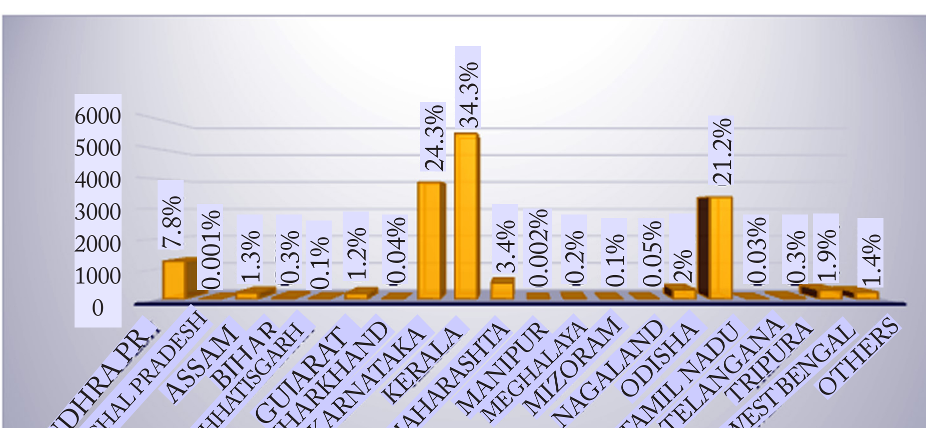


Fig.1.18 Production share of leading plantation producing states for 2019-20 (3rd advance estimate)

In India, Kerala is the largest area and production holder for Coconut with 807.13 thousand hectares and 5829 thousand tonnes, respectively. Karnataka is first in area and production of Arecanut, which is 254.64 thousand hectares and 517.35 thousand respectively (NHB, 2018).

Export of horticultural produce in India 2020-21

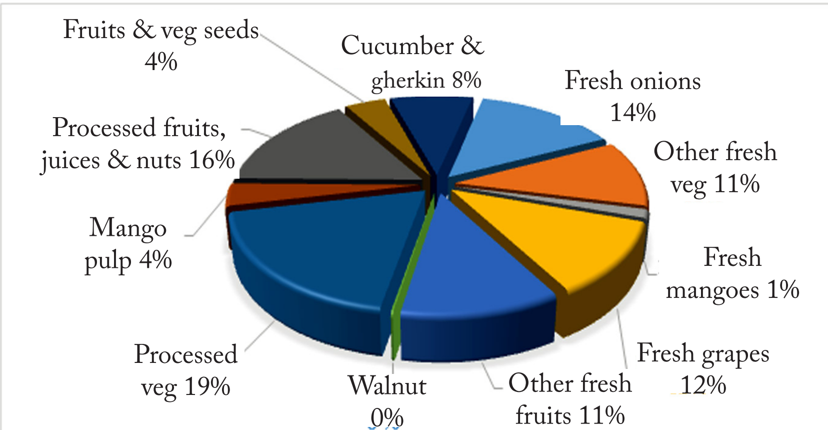
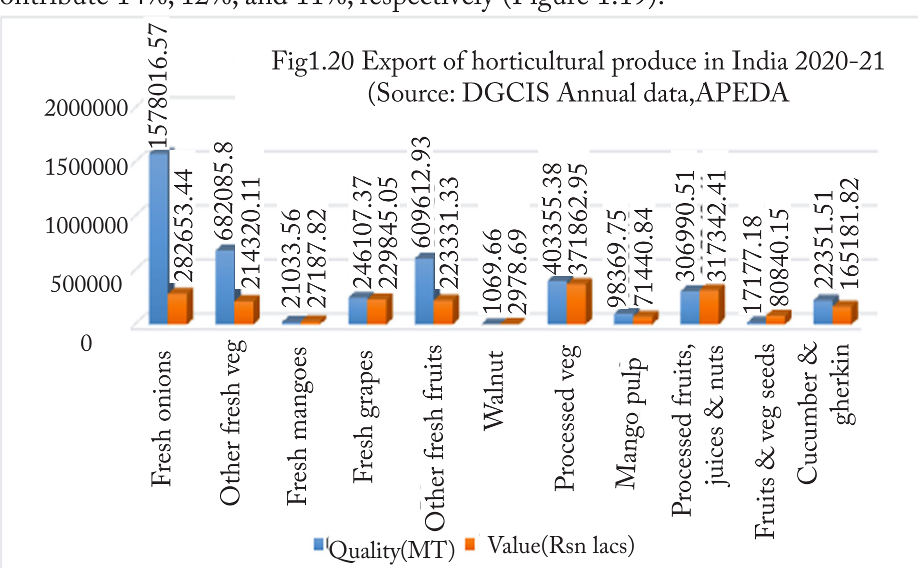


Fig1.19 Share contribution (%)

In 2020-21, the highest contribution to the export of Horticultural Produce is from processed vegetables which is 19 % followed by processed fruits, juices, and nuts which is 16%. Fresh onions, fresh grapes, and other fresh fruits and vegetables contribute 14%, 12%, and 11%, respectively (Figure 1.19).

Fig1.20 Export of horticultural produce in India 2020-21 (Source: DGCIS Annual data,APEDA



Fresh Onions contributes the highest earning value to the export of Horticultural Produce in India with a production quantity of 1578016.57 MT and a value of Rs.282653.44/-. The major destinations are Bangladesh, Malaysia, Sri Lanka, and United Arab Emirates. It is followed by other fresh vegetables, including cabbage, cauliflower, tomatoes, okra, and peas, with a value of Rs.214320.1/- (Figure 1.20).

India has come a long way from food insufficiency to sufficiency in the production of fruits and vegetables. However, the availability of the required recommendation in an adult's diet is yet to be achieved. The main constraint to the production of fruit and vegetable crops is due to improper and lack of cold storage facilities which results in tremendous post-harvest losses and reduced value of the crops. Horticultural produce has a huge potential in international markets, so efforts and priorities from the Indian government will serve as an impetus for an enhanced and efficient production of fruits and vegetables. This will lead to an increase in the value of the horticultural produce from exports and will thus play a part in improving the country's economy.

References

APEDA, India Export Statistics, 2020-21.

Department of Agriculture and Farmers Welfare, Horticulture Crops for 2020-21 (3rd Advance Estimate), 2019- Advance Estimate)

Dhandevi, P. E. M. and Jeewon, R. (2015). Fruit and vegetable intake: Benefits and progress of nutrition education interventions-narrative review article. *Iranian journal of public health*, **44**(10): 1309.

National Horticulture Database, 2018.

Sachdeva, S., Sachdev, T. R. and Sachdeva, R. (2013). Increasing fruit and vegetable consumption: challenges and opportunities. *Indian journal of community medicine: official publication of Indian Association of Preventive & Social Medicine*, **38**(4): 192.

Chapter - 2

Pesticides, its Residues and Environment

C.G. Sawant, L.D. Sharma and Rahul Sadhukhan

Introduction

Increasing food production is the foremost goal of all the developed, developing, and under-developing countries worldwide. The world population is continuously growing at a constant rate to reach about 10 billion by 2050. According to Saravi and Shokrzadeh, 2011, the world population is constantly increasing by an estimation of 97 million per year. An alerting forecast issued by the Food and Agricultural Organization (FAO) of the United Nations that world food production needs to be increased by 70 percent to meet the demand of a growing population worldwide. However, with this issue, the emphasis on food production is facing different and ever-growing challenges from climate change to the lack of quality inputs like seed and land, especially the new area that can be increased for cultivation is going to be very limited due to continues fragmentation and loss of fertility of agriculture lands (Saravi and Shokrzadeh, 2011). Therefore, a tremendous amount of pressure on the world population has been put on the existing agricultural ecosystem to meet food needs from the same current resources like land, water, labor, etc. During World War II (1939-1945), industries of pesticide production were increased because it was a need and urgency to enhance food production.

Meanwhile, in the 1940s, substantial growth of production of DDT, aldrin, dieldrin, endrin, parathion, and 2, 4-D as synthetic pesticides were recorded. These chemicals have mainly come into the focus since organochlorine (O.C.s) insecticides were first used for pest management in the agricultural ecosystem. After this substantial growth, in the 1950s decade, the application of pesticides in agriculture was considered advantageous with effectiveness. No concern about the potential risks of these pesticides to the environment and human health existed.

In cultivating the soil and increasing crop production to meet emerging demand, herbicides, insecticides, fungicides, nematicides, fertilizers, and soil amendments are now being used in higher quantities than in the past. Before introducing synthetic pesticides, weeds, insect pests, and diseases were controlled by using cultural, mechanical, and physical management strategies only by the farmers. The use of pesticides in the agricultural ecosystem is now an integral part of our day-to-day life and is used to protect agriculture, stored grain, flower gardens and eradicate the pests transmitting dangerous infectious diseases. It has been estimated that the worldwide agrochemicals market worth nearly $ 256.7 billion are spent on pesticides each year (Statista, 2021). This is expected to increase to almost 308.4 billion U.S. dollars in 2025. According to a report of the database Research and Markets, the Indian pesticides market was worth Rs 181 billion in 2017, further projected to reach INR 292.9 Billion., growing at a Compound Annual Growth Rate (CAGR) of 8.3 percent during 2018-2023 (Anon., 2018). In the last decades, manufacturers and researchers worldwide have been designing new formulations of pesticides to meet the global demand for food to secure human beings from hunger globally.

Farmers use a substantial amount of pesticides throughout crop growth and sometimes even at the fruiting and harvesting stages of crops. Indiscriminate use of pesticides, particularly during the fruiting stage and non-adoption of the safe waiting period, results in the accumulation of pesticide residues in foods, i.e., fruits, vegetables, cereals, pulses, eggs, meat, and fish. Moreover, the produce is harvested at a short interval and consumed fresh. Therefore, it is unwise to use pesticides alone to manage insect pests. A pesticide should be practical and economical but should not leave toxic residues in food. Being an ideal, the applied pesticides should only be toxic to the target organisms without producing harmful effects in an ecosystem, biodegradable, and eco-friendly to some extent (Rosell *et al.*, 2008). But unfortunately, most of the pesticides are non-specific, targetless, and may directly or indirectly kill the harmless or valuable organisms to the ecosystem. According to the estimation of Carriger *et al.*, 2006 in general, only about 0.1 percent of the pesticides reach the target organisms, and the remaining pesticides contaminate the surrounding environment. The repeated and indiscriminate use of persistent and non-biodegradable pesticides has polluted various ecosystem components, i.e., water, air, and soil ecosystem. Apart from this, most non-degradable pesticide residues have also entered into the food chain and food web of humans and wild animals and have bioaccumulated in the higher tropic level.

In 1962, American marine biologist and environment conservationist Rachel Louise Carson wrote and published a book, "Silent Spring." She mentioned problems and impacts that could arise due to the indiscriminate use of a pesticide like

DDT and is widely credited with helping to launch the environmental movement. Carson was not the first or the only person to raise concerns about DDT, but her combination of "scientific knowledge and poetic writing" reached a broad audience and helped to focus opposition to DDT use. In 2012 'Silent Spring' was designated a "National Historic Chemical Landmark" by the American Chemical Society for its role in developing the modern environmental movement. This book inspired widespread concern about the impact of pesticides on human health and the environment. Ratcliffe (1967) noted an increased incidence of raptor nests with broken eggs in the United Kingdom. This author showed that the sharp decline in eggshell thickness coincided with the beginning of the widespread use of DDT in agriculture (1945–1946). During the 1970s decade, the problem of pest resistance emerged, which combined with the awareness created by the book "Silent Spring" and accumulated evidence on the effects of pesticides, reached a climax in banning the use of DDT in USA in 1972. After that, other countries have also taken this evidence seriously and started to discontinue the use of DDT, as well.

Between the 1970s and 1980s emerged as a new era for introducing more selective pesticides with an advanced model of action than previous ones. After that, in the 1990s, scientists and researchers concentrated on finding new members of selective pesticides. During this period, safer chemicals arose, ensuring adequate quantities of high-quality crop production, essential for food supply, environmental concerns, and positive impacts on human health. Continuous and consistent efforts of scientists and researchers result in the emergence of new concepts or pest management systems, i.e., Integrated Pest Management (IPM) system, this was used for crop productions that attracted natural predators or parasites that attacked insect pests of different crops in the agricultural ecosystem and arrested the use of pesticides to some extent. However, this concept or system did not eliminate the need and use of pesticides. Still, the unwise and indiscriminate use of pesticides in high quantity causes a significant threat to the environment, agricultural ecosystem, and human health.

Despite the benefits of an old and new member of pesticide, it can be hazardous to humans, the agricultural ecosystem, and the environment. Numbers of pesticides are environmentally persistent, stable, prone to bioaccumulation, and toxic to the fauna and flora of the different ecosystems. Below, we have detailed the effect of pesticides on ecology, soil, water, and agriculture ecosystem.

Risks of Pesticide Use

Risks associated with the indiscriminate and unwise application of different pesticides to tackle the insect pest problems in various crops, gardens, lawns, and household pest control have surpassed their beneficial effects. The Indiscriminate and unwise application of pesticides produces drastic and harmful effects on non-target species of different organisms and adversely affects animal and plant biodiversity, aquatic and terrestrial food webs, and ecosystems. According to Majewski and Capel (1995), about 80-90 percent of the applied pesticides can volatilize within a few days of application. Such volatilization losses of applied pesticides are widespread and likely occur using pesticides through different plant protection appliances. Unwise and uncontrolled use of pesticides during all the crop growth stages in the agriculture ecosystem has resulted in a reduction of several terrestrial and aquatic animal and plant species. Despite this, indiscriminate use of pesticides, particularly during the fruiting stage and non-adoption of the safe waiting period, resulted in the accumulation of pesticide residues in foods, i.e., fruits, vegetables, cereals, pulses, eggs, meat, and fish, and sometimes the agriculture produce such as vegetables and fruits are harvested at a short interval to meet the demand of the market and consumed fresh. Additionally, different tropical levels in the air, water, and soil ecosystem have also being contaminated with these pesticides to harmful and threatening levels.

Among all the categories of pesticides, insecticides are proven the most toxic, whereas fungicides and herbicides are second and third in different tropical levels of diverse ecosystems. After applying pesticides, they entered the natural ecosystems and persisted in two different ways depending upon their solubility. Firstly water-soluble pesticides get dissolved in water and enter groundwater, streams, rivers, and lakes, causing harm to untargeted and valuable species. Secondly, fat-soluble pesticides enter the bodies of animals by a process known as “biomagnifications or bioaccumulation.” They get absorbed in the fatty tissues of animals, resulting in pesticide persistence in food chains for extended periods (Warsi, 2015). Pesticides can have short-term toxic effects on directly exposed organisms. Long-term effects can result from changes to habitats and the food chain in the worldwide Biodiversity of the different ecosystems.

Effect of pesticides and its residues on biodiversity

The risk associated with the indiscriminate use of pesticides cannot be overlooked. It is the need of the hour to consider the pesticide impact on populations of aquatic and terrestrial Biodiversity. Accumulation of pesticides in the food chains is the most significant concern as it directly affects the predators and raptors. But, indirectly, pesticides can also reduce the number of weeds, shrubs, and insects on which higher orders feed. Spraying of insecticides, herbicides, and fungicides have also been linked to declines in the species population of rare animals and birds.

Effect of pesticides and its residues on aquatic biodiversity

Pesticides can be persisted in rainwater, groundwater table, streams, rivers, lakes, and oceans water bodies. There are four significant ways by which pesticides can reach aquatic life.

- » Drift from pesticides sprayed areas
- » Leach through the soil profile
- » Carried as surface runoff
- » It may be accidental leakage

The persistent accumulation of pesticides and their residues in water bodies poses a significant threat to aquatic life. Pesticides used in agricultural farms, kitchen gardens, and lawns have been found in surface waters and water bodies such as ponds, streams, and lakes. Pesticides that are applied to land drift and reach aquatic ecosystems produce toxic effects on fishes and non-target organisms. Near about 80-90 percent of the dissolved oxygen is provided by the aquatic plants present at the bottom of water bodies which is the primary source of life sustainability for aquatic fauna. According to the study of Helfrich *et al.* (2009), reductions in the diversity of aquatic plants due to the leaching effects of hazards herbicides in oceans result in a drastic decrease in oxygen supply to fishes and thus ultimately reduced their productions and productivity. In general, concentrations of different pesticides in surface waters are higher in range than the leached into groundwater tables. However, this is because of aggregate effects of seepage of contaminated surface water from different farmlands and drift contamination, nonscientific methods used for disposal of pesticides, empty containers, and accidental leakages. Due to persistent runoff of non-degradable pesticides and their residues into the lakes, ponds, and rivers, aquatic Biodiversity is under severe threat, sometimes killing all the fish in a particular water body.

Atrazine is the most commonly used herbicide, which has proven toxic to some fish species, and it also indirectly affects the immune system of some amphibians (Forson and Storfer, 2006 and Rohr *et al.*, 2008). Repeated and persistent exposure to sublethal doses of some non-degradable pesticides can cause physiological and behavioral changes that reduce fish populations, such as abandonment of nests and broods, decreased immunity to disease, and decrease in the ability of avoidance to predators. Herbicides such as copper sulfate toxic to fish and other water amphibians at concentrations similar to those used to kill the plants at terrestrial ecosystems. Carbaryl is an insecticide found harmful for several amphibian species, whereas herbicide glyphosate is known to cause high mortality of tadpoles and juvenile frogs

(Relyea, 2005). Even small concentrations of malathion insecticide are sufficient to change the abundance and composition of plankton and periphyton population that consequently affected the growth and development of frog tadpoles (Relyea and Hoverman, 2008). Moreover, chlorpyriphos and endosulfan also cause severe threats to many amphibians (Sparling and Feller, 2009). Higher exposure to endosulfan can change the hepatic metabolism of fish like hepatic somatic index, smaller values of liver weight, histopathological and ultrastructural alterations. This particular result in restlessness, hyperactivity, irritation, difficulty in respiration as it moves to the surface to gulp air, rapid body movement, darkening of the color, loss of equilibrium by swimming sideways, and finally collapse and death occurred because of transfer of toxicity to the nervous system (Kenneth and Willem, 2010). Endosulfan acted as a growth suppressant, with the magnitude of its suppression in Zebrafish, in the order of female > male > juveniles. It affected sexual maturity in females and reduced the spawning frequency and cumulative fecundity by affecting the processes of egg maturation and vitellogenesis processes. It also affected males by postponing sexual maturity and reducing fertilizability by reducing the motility duration of the sperm (Relyea, 2009). Exposing tadpoles to the endosulfan at levels likely to be found in habitats near fields sprayed with the chemical kills the tadpoles and causes behavioral and growth abnormalities (Raloff, 1998).

A detailed study of Dr. Hayes showed that 10 percent of male frogs exposed to atrazine herbicide-contaminated water developed into females. Male frogs were genetically males but phenotypically developed ovaries within their testes. They also developed the tendency to mate with other males and lay sustainable eggs (Environmental Impacts, 2014). The reproductive potential of aquatic life also reduces due to hazardous herbicidal spraying to control herbs and weeds near fish nurseries, which eventually reduces the hiding place and shelter required for young fish to hide from predators (Helfrich *et al.*, 2009). Crocodiles, many turtle species, and some lizards species lack sex-distinct chromosomes until after fertilization during organogenesis, depending on temperature. Embryonic exposure in turtles to various PCBs (polychlorinated biphenyl) causes a sex reversal. Pesticides can accumulate in bodies of water to levels that kill off zooplankton, the primary source of food for young fishes. Pesticides can also kill off insects on which some fish feed, causing them to travel farther in search of food and exposing them to greater risk from predators.

Effects of pesticides and its residues on terrestrial biodiversity

Organisms exposed through primary consumption of highly toxic pesticides like insecticides, fungicides, rodenticides, and herbicides usually experience acute poisoning and chronic poisoning in both targeted and nontargeted organisms. The majority of pesticides in the market commonly produce chronic and sub-lethal effects because of the low level of residues. Some spectacular results associated with the use of pesticides studied by scientists and scholars are given below for more elaborative studies on terrestrial ecosystems.

Drifting or volatilization of phenoxy herbicides can cause injury to nearby trees and shrubs (Dreistadt *et al*., 1994). Frequently and more commonly used herbicide glyphosate increases the susceptibility of plants to diseases and reduces seed quality (Brammall and Higgins, 1988). Even low doses of herbicides, sulfonylureas, sulphonamides and imidazolinones have a devastating impact on the productivity of non-target crops, natural plant communities, and wildlife (Fletcher *et al*., 1993). The population dynamics of productive insects such as bees, silkworms, Hymenoptera parasites, parasitoids, and beetles can significantly decline by the indiscriminate and unwise use of broad-spectrum insecticides such as carbamates, organochlorines, organophosphates, and synthetic pyrethroids. It proved in many experiments and studies that the insect population has also been greater on organic treated fruits and vegetables than non-organic treated ones. Synergistic effects of synthetic pyrethroids insecticides and triazole or imidazole fungicides are harmful to honey bees (Pilling and Jepson, 2006.) Neonicotinoids insecticides such as clothianidin and imidacloprid were proved toxic to the many species of bees. The foraging behavior of many species of honey bees is negatively affected by the use of even a shallow dose of Imidacloprid (Yang *et al*., 2008) and reducing learning capacity. The greatest havoc wreaked by neonicotinoids was the sudden disappearance of honey bees at the very start of the twenty-first century. This was a major concern to the agriculture sector as 40-45 percent of the food production depends on activities of pollination performed by the various bees. The mixture of various organophosphorus and neonicotinoids pesticides was recorded in honey and wax obtained from commercial hives. Among various mixture neonicotinoids, groups shared a significant portion. Since 2006, honey bees and birds populations have dropped by 29 to 36 and 20 to 25 percent each year, respectively (Environmental Impacts, 2014). This massive decline is due to the results of the use of conventional pesticides in a very high amount without considering the environmental concerns that were not known before 1962. Bioconcentrations and biomagnifications or bioaccumulation of pesticides in the tissues of different bird species results in chronic poisoning and finally leads to their death. Bald eagle populations in the USA declined primarily because of prolonged exposure to DDT and its non-degradable metabolites (Liroff, 2000). Inappropriate application of monocrotophos over alfalfa fields to control voles in Israel resulted in the killing of hundreds of kites, eagles, buzzards, and owls in a few days because they fed on voles that had been affected by this O.P. insecticide (Mendelssohn and Paz, 1977). Applications of soil pesticides such as insecticides, fungicides, rodenticides, and herbicides can directly kill the earthworm life stages, indirectly reducing birds and mammal populations on which they feed. Organophosphate insecticides are highly toxic to birds, and they are known to have poisoned raptors in the fields. Sublethal quantities of pesticides can affect the nervous system, causing behavioral changes (Pesticides reduce Biodiversity, 2010). Pesticides can be applied on soil or crop plants, may be incorporated into the soil as granular form or as a seed treatment to treat the seed-borne or soil-borne insect pests. Once they have reached their target area, pesticides dissipate via the process of degradation, dispersion, volatilization, or leaching into surface water and groundwater table; they may be translocated via the xylem, or phloem vessels in plants or taken up by soil microbes, or they may stay in the soil as non-degrading metabolites (Hayo and Werf, 1996). Unwise and indiscriminate use of pesticides leads to their leaching into the soil profile, which affects the microbes residing in it. Soil-dwelling many microbes help the plants in many ways, such as nutrient uptake, breakdown of complex organic matter into the simple form, and increasing soil fertility. Unfortunately, pesticide overuse may have drastic consequences, and a time may come when we would not have any more of these organisms, and soil may degrade. Several soil microbes are involved in the fixation of atmospheric nitrogen to nitrates. Chlorothalonil and dinitrophenyl fungicides have been shown to disrupt nitrification and denitrification bacterial-dependent processes (Lang and Cai, 2009). Glyphosate, a non-selective world widely used herbicide, reduces the growth and development of nitrogen-fixing bacteria in soil (Santos and Flores, 1995.) whereas, 2, 4-D inhibits the transformation of ammonia into nitrates carried out by the different beneficial soil bacteria. Herbicides also cause considerable damage to many fungal species in soil. Herbicides trifluralin and oryzalin are both known to inhibit the growth of symbiotic mycorrhizal fungi, which helps in nutrient uptake (Kelley and South, 1978). Oxadiazon has been known to reduce the number of fungal spores, whereas triclopyr is toxic to certain species of mycorrhizal fungi (Chakravarty and Sidhu, 1987). Earthworms are key factors in soil that play a significant role in the soil ecosystem by acting as bioindicators of soil contamination and as models for soil toxicity testing. Earthworms also contribute to soil fertility. A pesticide harms the earthworms from their toxic effects, and the latter is exposed mainly via contaminated soil pore water. Schreck *et al*. (2008) studied and demonstrated that insecticides and fungicides produce neurotoxin, which affects the life cycle and diversity of earthworms. After long-term exposure, they are physiologically damaged. A well-known used herbicides glyphosate and insecticides chlorpyriphos have harmful effects on earthworms at the cellular level causing damage to DNA. Glyphosates affect the feeding activity and viability of earthworms

(Casabé *et al.*, 2007). Goulson (2013) reviewed the harmfulness of neonicotinoids on the environment and animal life. He also reported that as neonicotinoids tend to accumulate in the soil, they can kill earthworms such as *Eisenia foetida* species.

Effects of pesticides and its residues on humans health

Human health is directly and indirectly affected by the exposure of pesticides, especially conventional pesticides, due to their higher toxicity and persistence in the environment and ability to enter into the food chain in trace amounts as bioconcentration or biomagnification. Many hazardous and non-degradable pesticides can enter the human body via direct contact during manufacturing, sale, distribution, and application through food, especially fruits, vegetables, meat, fish, eggs, contaminated water, or polluted air. Some harmful effects of continuous exposure to pesticides are summarized below.

Immediate effects of pesticide exposure during application and intentional or unintentional poisoning generally leads to acute illness in humans causing several symptoms such as headache, irritation, and itching of the eyes and skin, irritation of the nose and throat, dizziness, body aches, cramps, diarrhea, rash and blisters on the skin, abdominal pain, nausea and vomiting, impaired vision, poor concentration, blindness, panic attacks and in severe cases coma and death due to pesticide poisoning. The severity of the symptoms mentioned above is generally associated with toxicity and quantity of used pesticides, mode of action, mode of application, length and frequency of contact with pesticides, and person exposure during application (Richter, 2002). Accidental exposure or overexposure to pesticides can have severe implications on human health. About 3 million cases are reported every year worldwide that occurs only due to acute poisoning of pesticides. Out of these 3 million cases, nearly 2 million cases are suicide attempts, and the rest are occupational or accidental poisoning while handling agricultural pesticides (Singh and Mandal, 2013). As in India, two in every three cases of poisoning happening because of pesticide consumption either intentionally or unintentionally. According to Chaitanya *et al.* (2021), a report involved 134 research studies done between January 2010 and May 2020, including more than 50,000 participants. It was revealed that pesticides were the leading cause of poisoning, with an overall prevalence of 63 percent due to widespread use and availability of pesticides for agricultural and household activities. The majority of pesticide poisoning in the adult population was 65 percent and 22 percent in children. An analysis of the region-wise distribution of the prevalence of poisoning showed that it was the highest in north India at 79 percent (more than three-fourths of the total cases of poisoning), followed by South India (65.9 percent), central India (59.2 percent), west India (53.1 percent), northeast India (46.9 percent) and east India (38.5 percent). The reasons for pesticide poisoning were the co-existence of poverty and agricultural farming and, thus, the easy availability of pesticides in rural areas.

Prolonged exposure to pesticides often leads to chronic and lethal effects on human health over long periods of years. Agricultural workers are at a higher risk of getting affected; however, the general population is also affected, primarily due to contaminated food and water or pesticides drifting from the fields (Pan-Germany, 2012). Chronic effects are long-term that can damage multiple body organs. Symptoms are not immediately apparent and manifest at a later stage. Pesticide exposure for prolonged periods results in many health complexes.

- Can cause a range of neurological health effects such as loss of coordination and memory, reduced visual ability, and reduced motor signaling (Lah, 2011).
- Can damage the immune system and cause hypersensitivity, asthma, and allergies (Culliney *et al.*, 1992).
- Pesticide residues and their metabolites have been accumulated and found in the bloodstream of cancer patients compared to healthy individuals. Prolonged exposure can be associated with other cancerous diseases like brain cancer, leukemia, lymphoma, breast cancer, prostate, ovaries, and testes.
- Biomagnification of pesticides residues and their metabolites in the body for a long time can affect reproductive potentials by altering male and female reproductive hormones. Consequently, it results in stillbirth, congenital disabilities, spontaneous abortion, and infertility (Pesticides and Human Health, 2014).
- Long-term exposure to pesticides also damages the liver, lungs, kidneys and may cause blood diseases.

Continuous exposure to organochlorine insecticides causes hypersensitivity to light, sound, touch, vomiting, nausea, dizziness, tremors, seizures, concentration loss, impaired vision, confusion, and nervousness (Lah, 2011). Prolonged exposure to organophosphates and carbamates insecticide causes symptoms similar to those of increased neurotransmitter-acetylcholine. These pesticides interfere with the normal nerve signal transduction, and exposure to them causes headaches, dizziness, confusion, nausea and vomiting, muscle and chest pain. Difficulty in breathing, convulsions, coma, and finally, death may occur in severe cases (Pesticides and Human Health, 2014). Pyrethroids can cause an allergic skin response, aggressiveness, hyper-excitation, reproductive or developmental effects, in addition to causing tremors and seizures (Lah, 2011). It is observed that there is a relationship between pesticides and Parkinson's disease and Alzheimer's disease (Casida and Durkin, 2013). Like this, chronic poisoning of pesticides is also known to induce heritable changes without alteration in DNA sequences through DNA methylation, histone modifications, and the expression of non-coding RNAs. For example, neurotoxic herbicide paraquat has been implicated in inducing Parkinson's disease (P.D.) through epigenetic changes by promoting histone acetylation (Song *et al.*, 2010). Pesticides may also cause oxidative stress by increasing reactive oxygen species (ROS) through altering levels of antioxidant enzymes such as superoxide dismutase, glutathione reductase, and catalase (Agrawal and Sharma, 2010). Several health problems such as Parkinson's disease, disruption of glucose homeostasis have been linked with pesticide-induced oxidative stress (Mostafalou and Abdollahi, 2012).

Conclusion

Although pesticides were used initially to benefit farmers and people worldwide through an increase in agricultural production and productivity and by controlling infectious diseases, weeds, and insect pests, their adverse effects cannot be overlooked. An issue of hazards pesticides to aquatic, terrestrial Biodiversity, and human health has raised concerns about the safety of pesticides. Although we cannot eliminate the use of pesticides but can be minimized risk associated by several ways, such as the production of better, safe, and environment-friendly pesticides and by alternative pest control strategies like IPM, which deploys a combination of different control measures viz., cultural control, use of resistant genotype, physical and mechanical control, and rational use of pesticide could reduce the amount as well as doses of pesticide applications. Creating awareness through community development and various extension programs that could encourage farmers to adopt the innovative IPM strategies is key to reducing the harmful impact of pesticides on our environment. If the pesticides are used wisely and discriminate manner and used only when necessary, pesticide risks can be minimized to some extent. The above discussion highlights the severe consequences of indiscriminate and improper pesticide use on different environmental components, including human health risks. Some of the adverse effects associated with pesticide application have emerged in the form of adverse effects and decline in aquatic Biodiversities, such as planktons, zooplanktons, different species of fish, crocodiles, turtles, etc. and terrestrial Biodiversities such as plants, bees, voles, birds, bald eagles, other microbes and earthworms' species, etc. through contaminated water and air ecosystem. The persistent and non-degrading nature of pesticides has produced harmful effects on an ecosystem to such an extent that pesticides have entered into various food chains of humans and other large mammals. Some of the acute and chronic poisonings that lead to illnesses in human health have now emerged due to the congregate effect of pesticides and its intake through polluted water, air, or food. Now, this is a need of an hour to rationalize the use of pesticides judicially to protect our environment and eventually human health hazards associated with it.

References

Agrawal, A. and Sharma B. 2010. Pesticides induced oxidative stress in mammalian systems: a review. *International Journal of Biological and Medical Research*,1:90-104.

Anonymous. 2018. Indian Pesticides Market: Industry Trends, Share, Size, Growth, Opportunity and Forecast, 2018-2023.

Brammall, R.A. and Higgins, V. J. 1988. The effect of glyphosate on resistance of tomato to Fusarium crown and root rot disease and the formation of host structural defensive barriers. *Can. J. Bot*., 66:1547–1555.

Carriger, J.F., Rand, G.M., Gardinali, P.R., Perry, W.B., Tompkins, M.S. and Fernandez, A.M. 2006. Pesticides of potential ecological concern in sediment from South Florida canals: an ecological risk prioritization for aquatic arthropods. *Soil and Sediment Contamination,* 15:21-45.

Casabé, N., Piola, L., Fuchs, J., Oneto,. M.L., Pamparato, L., Basack, S., Giménez, R., Massaro, R,, Papa, J.C. and Kesten E. 2007. Ecotoxicological assessment of the effects of glyphosate and chlorpyrifos in an Argentine soya field. *J. Soils Sedim.*,7:232–239.

Casida, J.E. and Durkin, K. A. 2013. Neuroactive insecticides: targets, selectivity, resistance, and secondary effects. *Annu. Rev. Entomol.,* 58:99–117.

Chaitanya, Mittal., Surjit, Singh., Praveen, Kumar, and Shoban, Babu, Varthya. 2021. Toxicoepidemiology of poisoning exhibited in an Indian population from 2010 to 2020: a systematic review and meta-analysis. *British Medical Journal*. 11(5): 1-9.

Chakravarty, P. and Sidhu, S.S. 1987. Effects of glyphosate, hexazinone and triclopyr on in vitro growth of five species of ectomycorrhizal fungi. *Eur.J. Pathol.,* 17:204–210.

Culliney, T.W., Pimentel, D. and Pimentel, M.H.1992. Pesticides and natural toxicants in foods. *Agric. Ecosyst. Environ*., 41:297–320.

Dreistadt, S.H., Clark, J.K. and Flint, M.L. 1994. Pests of landscape trees and shrubs. An integrated pest management guide. University of California Division of Agriculture and Natural Resources. Publication No. 3359.

Environmental Impacts. 2014. In: Pesticide Action Network. Available from http://www.panna.org/issues/persistent-poisons/environmental impacts. Accessed Dec 20, 2014.

Fletcher, J.S., Pfleeger, T.G. and Ratsch, H.C. 1993. Potential environmental risks associated with the new sulfonylurea herbicides. *Environ. Sci. Technol.,* 27:2250–2252.

Forson, D.D. and Storfer, A. 2006. Atrazine increases Ranavirus susceptibility in the tiger salamander (Ambystoma tigrinum). *Ecol. Appl.,* 16:2325–2332.

Goulson, D.J. 2013. An overview of the environmental risks posed by neonicotinoid insecticides. *J. Appl. Ecol.,* 50:977. doi: 10.1111/1365-2664.12111.

Hayo, M. G, and Werf, V.D. 1996. Assessing the impact of pesticides on the environment. *Agric Ecosyst Environ*., 60:81–96.

Helfrich, L.A., Weigmann, D.L., Hipkins, P. and Stinson, E.R. 2009. Pesticides and aquatic animals: a guide to reducing impacts on aquatic systems. In: Virginia Polytechnic Institute and State University. Available from https://pubs.ext.vt.edu/420/420-013/420-013. html. Accessed Jan 17, 2015.

Kelley, W.D. and South, D.B. 1978. *In vitro* effects of selected herbicides on growth and mycorrhizal fungi. Weed Sci. Soc. America Meeting. Auburn University, Auburn, Alabama: 38.

Kenneth, W. and Willem, S. 2010. Acute Toxicity and Lethal Body Burden of Endosulfan in Tilapia (*Oreochromis niloticus (L)*). *The Open Environmental Pollution & Toxicology Journal,* 2:21-26.

Lah, K. 2011. Effects of pesticides on human health. In: Toxipedia. Available fromhttp://www.toxipedia.org/display/toxipedia/Effects+of+Pesticides+on+Human+Health._Accessed Jan 16, 2014.

Lang, M. and Cai, Z. 2009. Effects of chlorothalonil and carbendazim on nitrification and denitrification in soils. *J. Environ. Sci.,* 21:458–467.

Liroff, R.A. 2000. Balancing risks of DDT and malaria in the global POPs treaty. Pestic Safety.

Majewski, M. and Capel, P. 1995. Pesticides in the atmosphere: distribution, trends, and governing factors. Pesticides in the hydrologic system, vol 1. *Ann Arbor Press Inc., Boca Raton, FL,* p 118.

Mendelssohn, H. and Paz, U. 1977. Mass mortality of birds of prey caused by Azodrin, an organophosphorus insecticide. *Biol. Conserv.,* 11(3): 163-170.

Mostafalou, S. and Abdollahi, M. 2012. Concerns of environmental persistence of pesticides and human chronic diseases. *Clinical and Experimental Pharmacology*; S5:e002. (http://dx.doi.org/10.4172/2161-1459.S5-e002). News 4:3. Pesticides reduce Biodiversity (June 2010) Pesticides News 88: 4–7.

Pan-Germany. 2012. Pesticide and health hazards. Facts and figures, 1-16 (www.pangermany.org/download/Vergift_EN-201112-web.pdf) (accessed on 14 October 2013).

Pesticides and Human Health. 2014. In: Californians for Pesticide Reforms. Available from http://www.pesticidereform.org/section.php?id=38. Accessed Jan 18, 2014.

Pesticides reduce Biodiversity (June 2010) Pesticides News 88: 4–7.

Pilling, E.D. and Jepson, P.C. 2006. Synergism between EBI fungicides and a pyrethroid insecticide in the honeybee (Apis mellifera). Pestic. Sci., 39:293–297.

Raloff, J. 1998. Common pesticide clobbers amphibians. Science News, Volume 154, Number 10, Page 150. Retrieved on 2007-10-15.

Ratcliffe, D.1967. Decreases in eggshell weight in certain birds of prey. *Nature;* 215: 208-210.

Relyea, R. A. and Hoverman, J.T. 2008. Interactive effects of predators and a pesticide on aquatic communities. *Oikos*, 117:1647–1658.

Relyea, R. A. 2005. The lethal impact of Roundup on aquatic and terrestrial amphibians. *Ecol Appl.*,15:1118–1124.

Relyea, R.A. 2009. A cocktail of contaminants: how mixtures of pesticides at low concentrations affect aquatic communities. *Oecologia*, 159, 363-376.

Richter, E.D. 2002. Acute human pesticide poisonings. *Encyclopedia of Pest Management.* 2002; 3-6.

Rohr, J.R., Schotthoefer, A.M., Raffel, T.R., Carrick, H.J., Halstead, N., Hoverman, J.T., Johnson, C.M., Johnson, L.B., Lieske, C., Piwoni, M.D., Schoff, P.K. and Beasley, V.R. 2008. Agrochemicals increase trematode infections in a declining amphibian species. Nature, 455:1235–1239.

Rosell, G., Quero, C., Coll, J. and Guerrero, A. 2008. Biorational insecticides in pest management. *Journal of Pesticide Science,* 33:103-121.

Santos, A. and Flores, M. 1995. Effects of glyphosate on nitrogen fixation of free-living heterotrophic bacteria. *Lett. Appl. Microbiol.,* 20:349–352.

Saravi S.S.S. and Shokrzadeh, M. 2011. Role of pesticides in human life in the modern age: a review. In: Stoytcheva M (ed.) Pesticides in the modern world-risks and benefits. *Intech.* p4-11.

Schreck, E., Geret, F., Gontier, L. and Treilhou. M. 2008. Neurotoxic effect and metabolic responses induced by a mixture of six pesticides on the earthworm *Aporrectodea caliginosa nocturna*. *Chemosphere,* 71(10):1832–1839.

Singh, B. and Mandal, K. 2013. Environmental impact of pesticides belonging to newer chemistry. In: Dhawan AK, Singh B, Brar-Bhullar M, Arora R (eds.). Integrated pest management. Scientific Publishers, Jodhpur, India; 2013. p152-190.

Song, C., Kanthasamy, A., Anantharam, V., Sun, F. and Kanthasamy, A. G. 2010. Environmental neurotoxic pesticide increases histone acetylation to promote apoptosis in dopaminergic neuronal cells: relevance to epigenetic mechanisms of neurodegeneration. *Molecular Pharmacology,* 77:621–632.

Sparling, D.W. and Feller, G.M. 2009. Toxicity of two insecticides to California, USA, anurans and its relevance to declining amphibian populations. *Environ. Toxicol. Chem.,* 28(8):1696–1703.

Statista. 2021. Agricultural chemicals market value worldwide in 2018 and 2019 with a forecast from 2020- 2025.

Warsi, F. 2015. How do pesticides affect ecosystems? In: Pesticides. Available from http://farhanwarsi.tripod.com/id9.html. Accessed Jan 16, 2015.

Yang, E.C., Chuang, Y.C., Chen, Y.L. and Chang, L.H. 2008. Abnormal foraging behavior induced by sublethal dosage of imidacloprid in the honey bee (Hymenoptera: Apidae). *J. Econ. Entomol.,* 101:1743–1748.

Chapter - 3

Pesticides, its Residues and Agriculture

Gagan Preet Kour Bali, Amritpal Singh Kaleka and C.G. Sawant

Introduction

"Diversity is at once a product, a measure, and foundation of system's complexity and therefore of its ability to support sustainable functioning" (Gliessman)

Agriculture is the cultivation of land for the advantage of selected species, including crops, trees, livestock, and grazing area. It acts as a critical component in promoting the global economy and supports the livelihoods and subsistence of the most significant number of people worldwide. Agricultural biodiversity is indispensable for plant stability and sustaining crop production, food security, and livelihoods for everyone. Agroecosystems are defined as the ecosystems in which the humans have exerted a deliberate selectivity on the composition of biota, i.e., the crops and livestock maintained by the farmer, replacing to a greater or lesser extent the natural flora as well as fauna of the site (Swift *et al*.,1996). Agriculture provides various ecosystem services and management practices utilized in the agroecosystems, which determine the state of the global environment (Tilman *et al*., 2002). Agroecosystems are characterized by both planned and unplanned diversity. Planned diversity includes the spatial and temporal arrangement of domesticated plants and animals that farmers purposely add to the system, along with beneficial organisms that are deliberately planned. Unplanned diversity includes weeds, herbivores, predators, microbes, and other microorganisms that persist in the system after its shift to agriculture or colonization from the surrounding landscape. Both have substantial effects on agroecosystem productivity, stability, pest regulation, and movement of organisms between cultivated fields and natural habitats in the agricultural landscapes (Alison, 2013).

Agroecosystems simultaneously provide and rely on ecosystem services. Zang *et al.* (2007) considered the services such as soil structure and fertility enhancement, nutrient cycling, water provision, erosion control, pollination, and pest control important which support the production of harvestable goods to agriculture and summarized in Fig.1.

The major ecosystem functions provided by agroecosystems are as

» The productivity of agricultural ecosystems depends on numerous species such as soil microorganisms, pollinators, predators of agricultural pests, and the genetic diversity of the crops and livestock.

» Agricultural ecosystems serve as important habitats for many wild plant and animal species. For example, wild species found in agricultural lands and nearby forests, wetlands, and other natural habitats play a crucial role in food security for many low-income farmers and rural people and provide valuable genetic resources for breeding certain plants.

» Ecosystem services provided by ecosystems other than agriculture, such as clean water, carbon regulation, nutrient cycling, or soil maintenance, are equally important to sustaining agricultural ecosystems.

Man has modified the landscapes to overcome the limits set by the environment and increase productivity, transforming land into cultivated fields, reclaiming wetlands, terracing slopes, and converting forests into pastures. This progress and use of modern technologies have also enhanced the environmental stress. Agriculture impacts the environment regarding the number of resources employed and substances, both natural and chemical; it generates which are released in various environmental compartments, soil, water, and atmosphere.

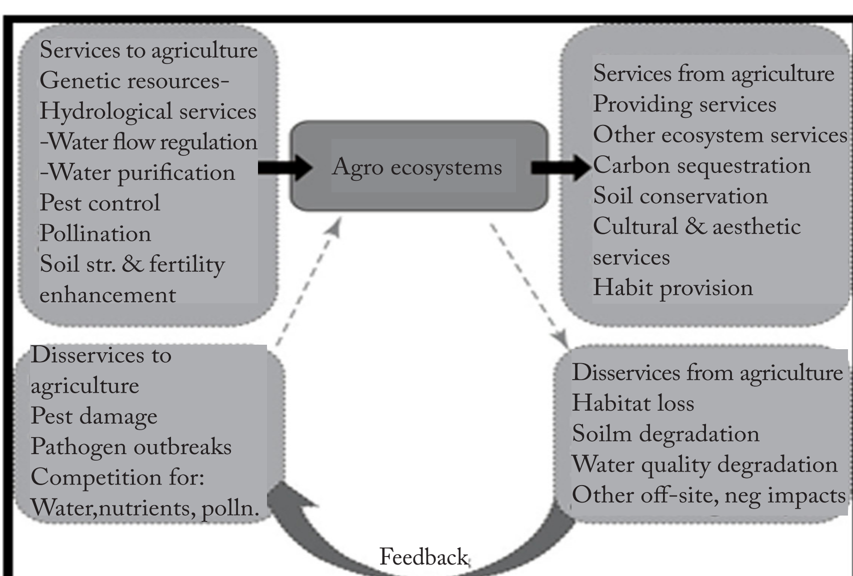


Fig. 3.1: Services to and from agroecosystems

Need of Pesticides

Pesticides are important as they help the farmers grow more food on minimum available space by protecting crops from pests, diseases, and weeds and raising their productivity per hectare. More than half of our crops would be lost to pests and diseases without pesticides. In addition, the pesticides enable farmers to produce safe, quality foods at affordable prices and help them to provide abundant nutritious food throughout the year. Crop quantity and quality rely on crop protection. In addition, pesticides decrease the chances of exposure to food contaminated with harmful microorganisms and naturally occurring toxins and thus help prevent food-related illnesses. In addition, the crop losses caused by pests, particularly by insects, are quite high in both developing and developed countries (Dhaliwal *et al.*, 2015).

Farmers use pesticides to

- » Protect the growing crops from pests, weeds, and fungal diseases.
- » Prevent rats, mice, flies, and other insects from contaminating foods during storage.
- » Safeguard human health by stopping food crops from being infected by fungi.

Initially, the pesticides helped conserve the environment and transformed the developing countries into breadbaskets for the rest of the world. The pesticides enable the farmers to produce more crops per unit area with less tillage, thus reducing deforestation, conserving natural resources, and curbing soil erosion. They also perform a critical role in controlling invasive species and noxious weeds. Using pesticides in stored products can prolong the viablilty of the produce, prevent huge postharvest losses from pests, diseases, and safeguard the grains for human consumption.

However, as pesticides are used to kill or control harmful organisms, unwanted pests, weeds, etc., they can harm people, other non-target organisms (wildlife), and the environment. For example, the extensive use of pesticides in agricultural production can degrade and even damage the soil biota (Gianessi *et al.*, 2005). However, due to their excessive use, the pesticides get assimilated in the environment, and their long-term application has disturbed the biochemical processes of the nutrient cycle.

Scenario of pesticides usage in India

In India, the production of pesticides started in 1952, with the establishment of a plant for BHC production near Calcutta (Mathur, 1999). Globally, India is the fourth-largest producer of agrochemicals after the U.S, Japan, and China, and according to published reports, the Indian pesticides market stood at 214 INR billion in 2019 (OECD-FAO, 2012). The Indian pesticide sector has a propensity to grow to INR 316 billion by 2024. India stands 12th in pesticide use globally and 3rd in Asia after China and Turkey (Gianessi *et al.*, 2005). An increase in demand for agricultural products to cope with the increasing population and commercialization of agriculture has enhanced the use of agricultural chemicals in India and other parts of the globe. An estimate predicted that 35-45 % of crop production is lost due to insects, weeds, and diseases in the fields, and the other 35 % accounts for storage losses. This naturally has facilitated the growth of the crop protection market (Devi *et al.*, 2017). The total pesticide consumption is highest in Maharashtra, followed by Uttar Pradesh, Punjab, and Haryana.

On the other hand, per hectare consumption of pesticides was highest in Punjab (0.74 kg), followed by Haryana (0.62 kg) and Maharashtra (0.57 kg) during 2016-17. The production and usage of pesticides are regulated in our country through the Insecticides Act, 1968 and Insecticides Rules, 1971. The Draft Pesticide Management Bill, 2017, was released by the Union Ministry of Agriculture and Farmers Welfare (MoAFW) for stakeholder comments on February 19, 2018. Subsequently, a new Pesticide Management Bill was created, and the Union Cabinet has now approved the same on February 12, 2020. This Pesticide Management Bill is of critical importance, as agriculture in India is mainly dependent on chemicals, including pesticides. Their overuse and misuse have a huge impact on human health, animals, biodiversity, and the environment (Vineet, 2020). The following points are of significant concern

- » Based on acute toxicity, the World Health Organization classifies certain pesticides as extremely hazardous (Class Ia) and highly hazardous (Class Ib). Therefore, necessary provisions must be made to ban the sale and use of Class I pesticides. In August 2018, the MoAFW banned 18 pesticides almost three years after the recommendations of the Anupam Varma Committee. But, it left out two heavily-used Class I pesticides, i.e., Monocrotophos and Carbofuran.
- » The efforts should be made to minimize the use of pesticides, recognizing that usage of such chemicals is not sustainable. It is a temporary stop-gap arrangement wherein the aim should be to use it as a last resort.
- » Inadequate representation and powers to the state governments is also a serious concern. State governments should be given more powers to regulate pesticide usage as they have a better idea about the agro-ecological aspects in their states.

» The provisions should be made to impose heavy fines and penalties as minor financial penalties would not be enough deterrence for pesticide companies with crores of turnover. For instance, a fine of Rs. 50,000 to 10,0000 for selling misbranded pesticides will not deter an industry giant from manufacturing such pesticides.

» Just like pharmaceutical drugs, the promotion of pesticides should be discouraged due to their hazardous nature. All kinds of such advertisements must be banned in India.

» Pesticides are hazardous chemicals with multiple, severe, and even fatal, acute, and chronic toxic effects, and these chemicals must be sold and used cautiously under proper supervision.

» The provision must be incorporated in the laws that make it illegal to sell a pesticide company without personal protective equipment or safety gear. The provision of systems and standard operating procedures for acute medical emergencies should also be made.

» Further, the legislative powers that regulate pesticides use should be transferred to the Union Ministry of Health and Family Welfare from the MoAFW to address health-related concerns without any conflict of interest (Vineet, 2020).

Pesticide Residues in Food

Pesticides residues show their presence in great variety in everyday foods and beverages, including instant cooked meals, water, wines, fruit juices, and even animal feeds (McGill and Robinson, 1968). These have also been detected in human breast milk samples, raising concern about prenatal exposure and health effects in children (Pirsaheb *et al.,* 2015). The accumulation of pesticide residues depends on the physicochemical properties of the pesticide molecules and food (Bajwa and Sandhu, 2014). The use of pesticides during production leads to insecticide residues in fruits and vegetables after harvest. Cucumber is the crop with the highest number of pesticide residues with the predominant presence of methomyl, metalaxyl, and imidacloprid. Methomyl is a carbamate insecticide with restricted use because of its toxicity to humans. Other pesticide residues found in cucumber samples include boscalid, chlorpyrifos, cyprodinil, fenhexamid, metalaxyl, and tebuconazole (Kostik *et al.*, 2014). The studies showed that many commodities contain more than one residue per product. Up to 5-9 residues were determined in citrus fruits like orange, mandarins, lemons, peaches, pears; followed by pomegranates, plums, cucumbers, tomatoes, strawberries with 3-5 residues, and grapes and tea with single residue. During the Brazilian pesticide residues monitoring program, apples, papayas, sweet peppers, and strawberries were found among the products with the highest percentage of samples with residues above the maximum residue limit. The high level of pesticide residues in pears, grapes, citrus fruit, peppers, cucumbers, tomatoes, carrots were observed in Lithuania (Petraitis *et al.,* 2013). The commodities with the highest level of pesticide residues found in China include cabbage, legumes, and leaf mustard (Chen *et al.,* 2011), and the insecticide residues reported in market samples of grapes were of acephate, methamidophos, chlorpyriphos, monocrotophos, and quinalphos (Reddy *et al*., 2000). A study on the analysis of pesticide residue concentration in vegetables revealed that the risk of pesticide contamination varied in different seasons and observed the winter season with the highest pesticide contamination in vegetables (Bhanti and Taneja, 2007).

In India, the Food Safety and Standards Authority of India sets the maximum residue limits for pesticides in crops, foods, vegetables, and fruits (Handford *et al.,* 2015). The Food and Agriculture Organization and World Health Organization have recommended residue limits for bioresmethrin, bromophos, Carbaryl, chlorpyrifos-methyl, deltamethrin, dichlorvos, etrimfos, fenitrothion, fenvalerate, malathion, methacrifos, permethrin, phenothrin, pirimiphos-methyl, and pyrethins used for the protection of grains (Amenze *et al.,* 2014). High level of pesticide residues was determined in imported blackberries, strawberries and other berries as well as mangoes, papaya, pepinos, bitter melon, peas, beans, eggplant, spinach, and other vegetables. In India, the first report of poisoning due to pesticides was from Kerala in 1958, where over 100 people died after consuming wheat flour contaminated with parathion (Karunakaran, 1958). This prompted the ICAR to constitute a Special Committee on harmful effects of pesticides to focus attention on the problem (Report of the Special Committee of ICAR, 1972).

Multiple pesticide residues have already been observed in some samples of canned foods, frozen vegetables, and fruit jams, which put consumers' health at risk of their adverse effects. For example, among 16,198 imported agricultural food products in Canada, 464 of 3193 residue findings exceeded MRL's, corresponding to a violation rate of 2.86 % (Neidert and Saschenbrecker, 1996). In Sweden, the published data on pesticide residues in domestically grown fruits and vegetables showed that the proportion of cases of reported residues was higher than 20 % of the MRLs. In addition, the residues in imported food crops of the same type increased from 31% to 37% (Ekstrom *et al.,* 1996). A list of 12 fruits and vegetables known as "Dirty Dozen" is of great concern due to pesticides, and strawberries, apples, grapes, tomatoes, and potatoes figure prominently among them (EL-Saeid *et al.*, 2000). In addition, the monitoring of pesticide residues in foods, fruits, and vegetables helps us to assess the potential risk of these products to consumer health and provides information and creates awareness about the pesticide treatments that have been used during the processes of agricultural harvesting, preservation, and distribution (Nayak and Solanki, 2021).

Fate of pesticides residues in vegetables and fruits

The pesticides sprayed on fruits and vegetables often accumulate on their outer peel or skin, the cuticle (Knoche and Lang, 2017). Some pesticides get absorbed by the plant surface (waxy cuticle and root surfaces) and enter the plant transport system (systemic) to protect it from the pests that penetrate the skin; other pesticides may stay on the plant surface (contact). During their stay on the plant surface, the pesticide is exposed to environmental factors such as wind and sun and washed off during rainfall. These pesticides can also undergo volatilization, photolysis, or chemical and microbial degradation (Keikotlhaile *et al.*, 2011).

The pesticide residues commonly accumulate on the peel or skin of the vegetables and fruits. For instance, thiabendazole and ortho-phenyl-phenol were detected in harvested citrus fruit peels (Taube *et al.,* 2002), residues of organochlorine pesticides (DDT and its derivatives, lindane, HCB) and organophosphorus pesticides (pirimiphos-methyl, dimethoate, malathion) were detected in potato skins (Soliman, 2001). Difenoconazole was detected in tomato skin (Kong *et al.,* 2012). In another study, Abou-Arab reported hexachlorobenzene, o.p-DDD, p.p-DDD, dimethoate, and profenophos two-seven times higher in the skin of tested tomatoes than in their pulp (Abou-Arab, 1999). In the same study, organophosphate (dimethoate and profenophos) residues were also detected in tomato seeds. In the same manner, hexythiazox, a non-systemic acaricide, which is applied on the fruit surface by contact mode and easily washed off, has also been observed in the pulp of treated strawberries (Saber *et al.*, 2015).

Effects of pesticides residues on agricultural ecosystems

Agriculture can contribute to ecosystem services but can also be a source of disservices, including loss of biodiversity, agrochemical contamination and sedimentation of waterways, pesticide poisoning of non-target species, and emissions of greenhouse gases and pollutants (Dale and Polasky, 2007). The primary ecosystem disservice from agriculture is the application of pesticides that result in loss of biodiversity and accumulation of pesticide residues in the surface as well as groundwater, which further degrades the water provisioning services provided by the agroecosystems. In addition, the pesticides exert a wide range of lethal (acute and chronic) and sublethal (often chronic) impacts on natural enemies, i.e., on bio-control agents (Stark *et al*., 2004). In 2008, Talebi and co-workers published a comprehensive review on the impact of pesticides on arthropod biological control agents (Talebi *et al*.,2008). Even the sublethal effects are expressed as some changes in the insect's life history attributes (Ruberson *et al*., 1998).

Pesticides are bioactive molecules that interfere with organisms' vital biochemical and physiological processes. Some are lethal to exposed organisms and cause disorder at the sublethal level. The environment persistence varies from pesticide to pesticide (Fernandez *et al.,* 2001). Some are persistent and remain in the environment either as a parent compound or transferred product. The soil composition, pH, moisture content, and microbial activities affect pesticide persistence. Pesticides act as the primary selective force in driving evolution in insect pests. The pesticide resistance may be associated with epigenetic modifications that influence gene expression's patterning without changing the underlying DNA sequence. The epigenetic modifications such as DNA methylation, histone modifications, and small RNAs are heritable in arthropods, but their role in the context of the rapid evolution of insecticide resistance is poorly understood. Brevik and co-workers described the supporting evidence that insecticide-induced effects can be transgenerationally inherited. Finally, they discussed that the epigenetic modifications are heritable and responsive to pesticide and xenobiotic stress. Therefore, the pesticide may drive the evolution of resistance via epigenetic processes (Brevik *et al.,* 2018).

The soil scientist Dr. Elaine Ingham stressed that if we lose both bacteria and fungi, then the soil degrades. The overuse of chemical fertilizers and pesticides has similar effects on soil organisms as the overuse of antibiotics on human health. Indiscriminate use of chemicals might work for a few years, but afterward, such chemicals are not beneficial to the soil as well as the organisms present in the soil to hold onto the nutrients" (Savonen, 1997). Presently, pesticides are common contaminants in soil, air, water, and non-target organisms, even in our urban landscapes.

Pesticides are often considered a quick, easy and inexpensive solution for controlling pests, particularly insect pests and weeds in rural and urban landscapes. However, the pesticide has contaminated almost every part of our environment. To sum up, based on our limited knowledge of direct and/or inferential information, the domain of pesticides illustrates a certain ambiguity in situations in which the people are undergoing life-long exposure (Akhtar *et al.,* 2009).

Conclusion

The agricultural biodiversity is indispensable for plant stability and sustaining crop production, food security, and livelihood for everyone. It is characterized by both planned and unplanned diversity. Agriculture impacts the environment concerning the quantity of resources employed and substances it generates, both natural and chemical, released in various compartments of the environment, i.e., soil, water, and atmosphere. The pesticides are used to kill or control harmful organisms, unwanted pests, weeds, etc., and can harm human health, wildlife (non-target species), and the environment. Globally, India is ranked fourth among the largest producer of agrochemicals after the U.S, Japan, and China. The pesticides are hazardous chemicals with multiple, severe, and even fatal, acute, as well as chronic toxic effects. Their residues can be observed in a great variety of foods and beverages, including instant cooked meals, water, wines, fruit juices, and animal feeds (Zang *et al.*, 2007). In addition, the Govt. should make provisions to sell and use these toxic chemicals cautiously under proper supervision. The ecosystem disservices from agriculture include applications of pesticides that result in loss of biodiversity and accumulation of pesticide residues in surface and groundwater, which further degrades water provisioning services. In addition, the proper monitoring of pesticide residues in foods, fruits, and vegetables can help us to create awareness and assess the potential risk of these toxins to consumer health.

References

Abou-Arab, A.A.K. 1999. Behavior of pesticides in tomatoes during commercial and home preparation. *Food Chem.*, 65: 509-514.

Akhtar, M.W., Senugupta, D. and Chowdhury, A. 2009. Impact of pesticides use in agriculture: their benefits and hazards. *Interdiscip. Toxicol.*, 2(1): 1-12.

Alison, G.P. 2013. Ecology of Agriculture. in Encyclopedia of Biodiversity (Second Edition), Volume 7, *Elsevier Science*. ISBN 978-0-12-384720-1 pp.5504.

Amenze, J.S., Tyohemba, R.L. and Ahile, U.J. 2014. Organochlorine pesticide residues analysis of postharvest cereal grains in Nasarawa State, Nigeria. *Int. J. Agron. Agri. Res.* 5(5): 59-64.

Bajwa, U. and Sandhu, K.S. 2014. Effect of handling and processing on pesticide residues in food- a review. *J. Food Sci. Technol.*, 51(2): 201-220.

Bhanti, M. and Taneja, A. 2007. Contamination of vegetables of different seasons with organophosphorus pesticides and related health risk assessment in northern India. *Chemosphere*. 69(1): 63-68.

Brevik, K., Lindstorm, L., Mckay, S.D. and Chem, Y.H.2018. Transgerational effects of insectides-implications for rapid pest evolution in agroecosystems . *Curr. Opin. Insect. Sci.,* 26: 34-40.

Chen, C.,Qian, Y. and Chen, Q. 2011. Evaluation of pesticide residues in fruits and vegetables from Xiamen, China. *Food Control*., 22(7): 1114-1120.

Dale, V. H. and Polasky, S. 2007. Measures of the effects of agricultural practices on ecosystem services. *Ecol. Econ.,* 64: 286-296 (doi:10.1016/j.ecolecon.2007.05.009)

Devi, P.I., Thomas, J. and Raju, R. K. 2017. Pesticide consumption in India: A spatiotemporal analysis. *Agril. Econ. Res. Rev*., 30(1): 163- 172. doi: 10.5958/0974-0279.2017.00015.5.

Dhaliwal, G. S., Jindal, V. and Mohindru, B. 2015. Crop Losses due to insect pests: Global and Indian Scenario. *Indian J. Entomol.,* 77(2): 165-165. Retrieved from: https://dx.doi.org /10.5958/0974-8172.2015.00033.410.5958/0974 8172.2015.00033.4

Ekstrom, G., Hemming, H. and Palmborg, M. 1996. Sweedish pesticide risk reduction 1981-1995: food residues, health hazard and reported poisonings. *Rev. Environ. Contam. Toxicol*., 147: 119-147.

EL-Saeid, M.H. and Shaht, M. 2000. Detectionof pesticide residues and heavy metals in some fresh fruits and vegetables collected from Cairo.1st Mansoura *Conf. of Food and Dairy Tech*.. 17-19 October, Cairo, Egypt. 183-203.

Fernandez, M., Rodriguez, R., Pico, Y. and Manes, J. 2001. Liquid chromatographic-mass spectrometric determination of postharvest fungicides in citrus fruits. *J. Chromatogr. A.,* 912(2):301-310.

Gianessi, Leonard, P. and Nathan, Reigner. 2005. The Value of Fungicides in U.S. Crop Production. Available online: http://croplifefoundation.files.wordpress.com/2012/07/completed-fungicide-report.pdf.

Handford, C.E., Elliott, C.T. and Campbell, K. 2015. A review of the global pesticide legislation and the scale of the challenge in reaching the global harmonization of food safety standards. *Integr. Environ. Assess. Manag.* 11(4): 525-536.

Karunakaran. 1958. C.O. The Kerala food poisoning. *J. Indian Med. Assoc.* 31: 204.

Keikotlhaile, B.M., Spanoghe, P., Mebdoua, S., Keikotlhaile, B.M. and Spanoghe, P. 2011. Pesticide residues in fruits and vegetables. In Bioactive Molecules in Food; Stoytcheva, M., Ed.; InTech: Rijeka, Croatia, p. 39. ISBN 978-953-307-532-7.

Knoche, M. and Lang, A. 2017. Ongoing growth challenges fruit skin integrity. *CRC Crit. Rev. Plant Sci*., 36: 190-215.

Kong, Z., Dong, F., Xu, J., Liu, X., Zhang, C., Li, J., Li, Y., Chen, X., Shan, W. and Zheng, Y. 2012. Determination of difenoconazole residue in tomato during home canning by UPLC-MS/MS. *Food Control*., 23: 542-546.

Kostik, V., Angelovska, B. and Kiroska-Petreska, E. 2014. Determination of pesticide residues in plant-based foods from the Republic of Macedonia. *J. Food Nut. Sci.,* 2(4): 124-129.

Mathur, S.C. 1999. Future of Indian pesticides industry in next millennium. *Pesticide Information*., 24(4): 9-23.

McGill, A.E., and Robinson, J. 1968. Organochlorine insecticide residues in complete prepared meals: a 12-month survey in S.E. England. *Food Cosmet. Toxicol*., 6:45-57.doi:10.1016/0015-6264(68)90080-1.

Nayak, P., and Solanki, H. 2021. Pesticides and Indian agriculture- a review. *Int. J. Res.- Granthaalayah*., 9(5): 250-263. doi: 10.7821/granthaalayah.v9.i5.2021.3930.

Neidert, E. and Saschenbrecker, P.W. 1996. Occurrence of pesticide residues in selected agricultural food commodities available in Canada. *J.AOAC Int.,* 79(2): 599-566.

OECD-FAO Agricultural Outlook. 2012. The organization of Economic Co-operation and Development and Food and Agriculture Organization of the United Nations. Available online: https://www.oecd-ilibrary.org/agriculture-and-food/oecd-fao-agricultural-outlook-2012_agr_outlook-2012-en.

Petraitis, J., Jarmalaitė, I. and Vaičiūnas, V. 2013. A review of research studies into pesticide residues in food in Lithuania, *Zemdirbyste-Agri.,* 100: 205-214.

Pirsaheb, M., Limoee, M., Namdari, F. and Khamutian, R. 2015. Organochlorine pesticides residue in breast milk: a systematic review. *Med. J. Islam Repub. Iran*., 29:228.

Reddy, J.D., Rao, N.B. and Sultan, A.M. 2000. Insecticide Residues in market samples of grape berries. *Pesto*., 16 (9): 17-22.

Ruberson, J.R., Nemoto, H. and Hirose, Y. 1998. Pesticides and Conservation of Natural Enemies in Pest Management, In: Conservation Biological Control, P. Barbosa, (ed.), 207-220, Academic Press, ISBN 978-0-12-078147-8, New York.

Saber, A.N., Malhat, F.M., Badawy, H.M.A. and Barakat, D.A. 2015. Dissipation dynamic, residue distribution, and processing factor of hexythiazox in strawberry fruits under open field condition. *Food Chem*., 196: 1108-1116.

Savonen, C. 1997. Soil microorganisms object of new OSU service. *Good Fruit Grower.,* Available online. http://www.goodfruit.com/archive/1995/6other.html.

Soliman, K.M. 2001. Changes in concentration of pesticide residues in potatoes during washing and home preparation. *Food Chem. Toxicol*., 39: 887–891.

Stark, J.D., Banks, J.E. and Acheampong, S. 2004. Estimating Susceptibility of Biological Control Agents to Pesticides: Influence of Life History Strategies and Population Structure. *Biol. Control*., 29(3): 392-398, ISSN 1049-9644.

Swift, M.J., Vandermeer, J., Ramakrishnan, P.S., Anderson, J.M., Ong, C.K., and Hawkins, B.A.,1996. Biodiversity and agroecosystem function. In: Functional roles of biodiversity: A global perspective, Cushman , J.H., Mooney, H.A., Medina, E., Sala , O.E., Schulze, E. D. (Eds.),John Wiley & Sons, Chichester. pp. 261-298.

Talebi, K., Kavousi, A. and Sabahi, Q. 2008. Impacts of Pesticides on Arthropod Biological Control Agents. *Pest Technol*., 2(2): 87-97. ISSN 1749-4818.

Taube, J., Vorkamp, K., Forster, M. and Herrmann, R. 2002. Pesticide residues in biological waste. *Chemosphere*., 49: 1357-1365.

Tilman, D., Cassman, K.G, Matson, P.A., Naylor, R. and Polasky, S. 2002. Agricultural sustainability and intensive production practices. *Nature*, 418:671-677.

Vineet, K. 2020. Pesticide management Bill 2020 must address important concerns. Available online: https://www.downtoearth.org.in/blog/agriculture/pesticide-management-bill-2020-must-address-important-concerns-69303.

Zhang, W., Ricketts, T.H., Kremen, C., Carney, K. and Swinton, S.M. 2007. Ecosystem services and dis-services to agriculture. *Ecol. Econ*., 64:253-260.

Chapter - 4

Pesticides, its Residues and Health Issues

Gagan Preet Kour Bali, Amritpal Singh Kaleka and C.G Sawant

"The soil is our external metabolism. It must be free of herbicides & pesticides, or the body cannot heal."- Dr. Max Gerson

Introduction

Pesticides are a category of chemicals formulated to kill or repel a pest or halt its reproduction and encompass a broad range of products, including herbicides, fungicides, insecticides, rodenticides, wood preservatives, and many other substances. The essence of such chemicals remains constant as these are poisonous but must be effective against the target organisms and safer for non-target organisms and environments. Presently, these chemicals take place in most of our environment, including workplaces, homes, and schools, in food and the community at large in our drinking and recreational waters, the air, soot, and soil.

Pesticides have proved a boon for farmers around the world by increasing agricultural yield. They act as indispensable tools in pre-harvest and post-harvest losses by combating damage from pests and thus ensuring sustainable food production with improved yield and greater food availability throughout the year. They plan a vital role in protecting people from devastating health risks like vector-borne infectious diseases such as malaria, dengue, Zika, Lyme disease, and West Nile virus. For instance, mosquito nets treated with insecticides are recommended to control the spread of malaria by WHO & UNICEF. Some pesticides, especially persistent organophosphates, used in regulated form for public health are banned in agricultural practices. They are commonly used in various ways, including lawn sprays and household bug sprays. They can be found in varying amounts in food such as strawberries, blueberries, apples, etc. But the environment and human health are drastically altered and harmed by the harmful effects of pesticides. Being the largest producer of pesticides in Asia, India is ranked on 12th position in the usage of pesticides globally (Sharma and Singhvi, 2017). The future of humanity relies on sustainable patterns in agricultural cropping systems. The current agricultural cropping and production system has reached its limits and has become unsustainable (Polyxeni *et al.*, 2016). The intensive use of pesticides is the primary cause of the decline in the farming system. The factors that derive the use of pesticides among farmers who produce 80 % of the world's food include limited availability of education for pesticide management and advice on alternative methods; subsides and foreign government donations, and the informal market in discount often illegal pesticides (Williamson *et al.*, 2008). The pesticide residue problem is serious in India, although the average Indian consumption is far less than in many developed countries (Abhilash and Singh, 2008). For sustainable agriculture and protection of the environment and human health, the importance of using safe pesticides has assumed global importance after the Earth summit in 1992. In developing countries, the effects of acute poisoning due to exposure to dangerous levels of pesticides in food are more severe in industrialized countries. In some regions, direct contact with pesticides used in agriculture is a widespread problem.

Pesticide Poisoning

Since pesticides are designed to be toxic to specific living organisms, there are concerns that some may also have human toxicity levels. The hazards of pesticides cannot be ignored, although their use has helped economic gains through crop protection. Their indiscriminate and extensive use seriously affects human health and non-target plants and animals by accumulating in food and water. Pesticides also lead to additional problems such as killing natural enemies of pests and more pest outbreaks, making many secondary pests resistant. Due to this situation, farmers tend to use more pesticides to prevent further crop losses due to pest outbreaks (F.A.O., 1995). Exposure to pesticides both occupationally and environmentally leads to a wide range of human health problems. Nearly 10,000 deaths were reported annually worldwide due to pesticides, about three-fourths of these occurring in developing countries (Horrigan *et al.*, 2002). In 1958, the first case of pesticide poisoning was reported in Kerala, in which over 100 people died after consuming wheat flour contaminated with parathion (Gupta, 2004). In India, 51 % of foods commodities are contaminated with pesticide residues, and out of these, 20 % have pesticides residues above maximum residue level values ((Gupta, 2004). The maximum contamination was reported in milk products (85 %) in Punjab (Menon, 2007). The pesticide residues reach groundwater and as well as reside on the edible parts of the crop. This is a matter of great concern as pesticides are entering the food chain making humans most susceptible due to their top position at the food chain.

Pesticides, its Residues and Health

Most pesticides are persistent, i.e., they do not break down into safer constituent parts but rather remain intact over prolonged periods and readily accessible to the human body. Another concept is toxicology which applies to understanding human health effects associated with exposure, is potency.

Not all pesticides are equally potent or have the capacity to create the same level of health threat. Toxicity depends on the type of pesticide, mode of entry, dose, metabolism, and pesticide accumulation. The existence of persistent chemicals in the environment and their effects on mankind and wildlife is a serious global concern. The awareness among the masses is improving risk-benefit ratio site, but even their correct usage harms non-target species and environment (Menon, 2007).

The effects on health depend on various factors related to the product, the characteristics of the exposure, and the host's condition. Pesticides affect different people differently. Not all age groups within the entire population face the same health hazards due to pesticide exposure. Because of various risk factors like larger body surface concerning body weight, differences in metabolism, higher growth rate, ongoing development of the body organs (Delaplane, 2000). Children are more prone to such chemicals than adults. While playing on floors or in lawns, the chances of their exposure to such chemicals increase. Their developing bodies may not break down these chemicals in an effective manner as compared to adults. Exposure to pesticides, whether occupational or residential to both paternal and maternal, has been linked to still births and increased risk of foetal deaths leading to an elevated risk of spontaneous abortions (Delaplane, 2000; Bornman *et al.*, 2017). The most common congenital disabilities in children generally studied to a relationship with pesticide exposure include mouth and face clefts and defects in limbs and neural tubes (Watts and Meriel, 2013). The children whose mothers had occupational contact with pesticides showed a developmental delay of up to 2 years and exhibited a deficit in motor speed, coordination, and visual memory. Even the children are found at higher rates of attention deficit hyperactivity disorder at age three and lower full-scale I.Q.s and working memory through age 7 with chlorpyrifos (organophosphate) exposure in the womb (Bell *et al.*, 2012).

Short exposure to some pesticides can cause poisoning of varying severity and is potentially lethal (Roberts *et al.*, 2012). It is short-term, can be geographically limited, and is generally related to a single pesticide (Virgina *et al.*, 2011). The impact on health on low-level chronic exposure to pesticides can occur via inhalation/ ingestion, dermal contact, or across the placenta. Biomarkers have been reported to exist for some pesticides in blood serum, semen, ovarian follicular fluid, amniotic fluid, umbilical cord blood, breast milk, and urine (Badii and Landeros, 2007). Acute poisoning is a persistent problem among agricultural and occupational workers who handle pesticides and track them into their homes where other family members get exposed. Mixing and applying pesticides can result in acute poisoning due to uptake through the respiratory organs or direct contact with skin or eyes.

Chronic effects of mammals of complete commercial formulations of pesticides are never tested. Only short-term acute toxic effects are studied (Colborn, 2006). Chronic toxicity interrupts the metabolic and systemic functions of the human body. The chemical constituents present in pesticides disrupt neurological functions and threaten immune and endocrine systems (Mesange and Seralini, 2018). Many pesticides are endocrine disruptors and can affect the functioning of hormones in the human body (Wesseling *et al.*, 1997). Chemical substances like cyhalothrin, amitrole, pyrimethanil, and fipronil inhibit the production of thyroid hormones. The thyroid hormone levels are altered by pesticides that potentially cause thyroid disorders. Even exposure to certain pesticides can disrupt sex hormones. The increased pesticide exposures decrease the fertility in both sexes of humans (Mandrich, 2014). The ingestion of organophosphates (O.P.P.s) is the main cause of insecticide-induced deaths in humans. It results in cholinergic syndrome, including syndromes like headache, slurred speech, coma, blurred vision, convulsions, respiratory blockage, and delayed neuropathy (Allsop *et al.*, 2015). Even the survivors of acute O.P.P.s poisoning suffer long-term effects on the nervous system (Mandrich, 2014). The increased levels also trigger the chances of neurodegenerative diseases like Alzheimer's and Parkinson's disease. They disrupt the enzymatic functions and signaling mechanisms at a cellular level. DNA based studies indicated that gene expression is affected by pesticides and transferred to successive generations through epigenetic inheritance (Bjorling *et al.*, 2008).

The recent studies showed a positive correlation between high pesticide exposures and chances of occurrence of cancer such as prostate cancer or lung cancer. Even the women with occupational herbicide or pesticide exposures had a significantly increased risk for meningioma relative to those who were never exposed to such chemicals (Samanic *et al.*, 2008). Kutros *et al.* indicated the association of two imidazonlinone herbicides (imazethapyr and imazaquin) with bladder cancer (Koutros, *et al.*, 2015).

The toxic nature of pesticides is usually not appropriately estimated. The pesticides are always commercialized as a mixture of ingredients, and all ingredients are not regulated and tested for their possible effects on human health. The surfactants, also named "inerts" or "formulants," are poorly tested, although these can be the most toxic ingredients in a pesticide formulation (Human Exposure to Environmental Chemicals, 2017). Mullin and his co-workers described the organosilicon surfactants as potent standalone pesticides and toxic to honey bees resulting decline in their health (Mullin *et al.*, 2016). The role of solvents in the toxicity of pesticides is well characterized, and most incidences of intoxication caused by organo-phosphorous pesticides can be attributed to their solvent content. Mesange and Antoniou made specific recommendations to protect the public from toxicity that may arise due to the ingestion of adjuvants of pesticides (Mesnage and Antoniou, 2018). The recommendations are as under:

1. Bio-monitoring of different human population groups to identify the true body burden of adjuvant classes of chemicals.
2. Surveying of food products to accurately identify sources of exposure.
3. Long-term laboratory animal toxicity studies comparing commercial formulations with their active principle to measure adverse outcomes stemming from the adjuvants.
4. The gaps in knowledge and consequent uncertainties in risk assessment concerning the toxicity of chemical mixtures, including adjuvants, need to be acknowledged by regulators. Thus, an additional safety factor needs to be added when calculating MRL and A.D.I. values.
5. All ingredients used in commercial formulations of pesticides should be subjected to the same risk assessment. The classification as inert or active has no scientific basis.

Mitigation of harmful effects of pesticides and its residues

The prevention of exposure to pesticides is the best remedy. Agroecology considers the social aspects of building sustainable and fair food systems and to reduce the usage of pesticides through it is the effective way. Agro-ecology links local economies and markets based on local solutions and builds resilience to climate change among communities. The use of alternative methods like integrated pest management (I.P.M.), crop rotation, organic farming, etc., by farmers can avoid the harmful effects of pesticides on human health. A three prolonged strategy to reduce the health impacts of pesticides was suggested by Cole *et al.*, 2002 which includes:

1. A community-based process of education and provision of personal protective equipment to reduce pesticide use.

2. Educating farmers to enhance agro-ecosystems in understanding to reduce pesticide use.

3. Policy intervention to restructure incentives and reduce the availability of highly toxic insecticides.

The education on modern trends of health and environmentally friendly pesticide application methods, including wearing protective clothing, should be emphasized for the farmers by extension agents to reduce the extent of exposure to pesticides (Adekunle *et al*., 2017). Effective working towards systemic change requires pesticide manufacturing companies to establish explicit core business policies to communicate, enforce, and monitor the supply chain (Food and Agriculture Organization, 2017).

Governments often struggle to maintain a responsible balance between necessary pesticide usage and reducing adverse health and environmental risks (Pesticide Action Network the Asia Pacific, 2020). The fourth version of the International code of conduct on Pesticide Management (2014) provided a framework that guides government regulators, the private sector, civil societies, and other stakeholders on best practices in managing pesticides. Many ways have been figured out by government legislature bodies considering children's specific vulnerabilities to reduce the risk of hazardous pesticides. Some of them are as:

a. Ban highly hazardous pesticides.

b. Require childproof containers and local language labeling of containers.

c. Prohibit aerial spraying.

d. Implement a national poisoning programme.

e. Improve risk assessment.

f. Establish explicit labour policies.

g. Build evidence and awareness.

There is an urgent need for accurate evaluation that depends on consistent, comprehensive, and targeted data. The primary purpose is to create awareness about different exposure pathways to pesticides and their associated impacts on human health. There must be facilities for additional research and modifications in core business policies and robust government legislation for continued monitoring and evaluation to ensure the implementation of efforts.

Conclusion

The application of pesticides has revolutionized global food production and helping the world to alleviate hunger, providing access to a nutritious and abundant food supply. But their widespread and improper use has led to unnecessary exposure of the world population to the pesticide. Limitation of exposure to chemical pesticides and usage of low-toxicity pesticides is the key to reduce the health hazards of pesticides. Current agricultural practices are primarily based on the wide use of chemical pesticides associated with negative impacts on human health, wildlife, and the natural environment (Zheng *et al.*, 2015). An urgent need for sustainable agricultural practices is required based on a dramatic reduction in the application of chemical pesticides. Developing a pesticide-free zone by implementing a total ban on the local level and in urban green spaces is highly recommendable. Last but not least, education and awareness on modern trends of health and environment-friendly pesticide application methods should be emphasized on a large scale.

References

Abhilash, P.C., and Singh, N. 2008. Pesticide use and application: An Indian scenario. *J. Hazardous Materials*, 165: 1-12.

Adekunle, C.P., Akinbode, S.O., Akerele, D., Oyekale, T.O. and Koyi, O.V., 2017. Effects of agricultural pesticide utilization on farmers' health in Egbeda local government area, Oyo State, Nigeria. *N.J.A.E.*, 7(1): 73-88.

Allsop M., Huxdorff C., Johnston P., Santillo D. and Thompson K. 2015. Pesticides and Our Health a Growing Concern. Greenpeace Research Laboratories, School of Biosciences, Innovation Centre, University of Exeter, Exeter, U.K. Available at: <www.ncbi.nlm.nih.gov/pmc/articles/PMC3237355>.

Badii M. and Landeros J. 2007. Pesticides that affect human health and sustainability. *Sci. Techno. Cul.,* 4: 21-34. < https://erevistas.uacj.mx/ojs/index.php/culcyt/article/view/454 >.

Bell, E. M., Hertz, P. I. and Beaumont, J. J. 2001. A Case-Control Study of Pesticides and Fetal Death Due to Congenital Anomalies. *Epidemiology*. 12(2): 148-156.

Bjorling P.M., Andersen H.R. and Grandjean P. 2008. Potential developmental neurotoxicity of pesticides used in Europe. *Environ. Health*. 7: 50.

Bornman, M.S., Natalie, H.A., Christiaan, J., Gesina, M.W., Hindril, B., Irene, E.J., Sean, M.P., Laura, N.V., Andreas, K., Bruce, B., Sarah, K., Bernard, J., Jacques, A. Joseph, D. and Jerrold, J.H. 2017. Endocrine Disruptors and Health Effects in Africa: A call for action. *Environ. Health Perspect.* 125(8): 1-10. Available online at: <https: //ehp.niehs.nih.gov/EHP1774/ f>.

Colborn T. 2006. A case for revisiting the safety of pesticides: A closer look at neurodevelopment. *Environ. Health Perspect*. 114(1): 10-17.

Cole D.C., Sherwood S., Crissman, C., Barrera, V. and Espinosa, P. 2002. Pesticides and health in high land Earadorian potato production-assessing impacts and developing responses. *Int. J. Occupational & Environmental Health*. 8:182-190.

Delaplane K. S. 2000. Pesticide Usage in the United States: History, Benefits, Risks, and Trends. http://pubs.caes.uga.edu/caespubs/pubs/PDF/B1121.pdf.

Food and Agriculture Organization of the United Nations. Agroecology Knowledge Hub: Overview, F.A.O., Rome, 2017. Available online at: www.fao.org/ agroecology /overview/en.

Gupta, P.K. 2004. Pesticide exposure-Indian Scene. *Toxicology*.198:83-90.

Horrigan, L., Lawrence, R.S., and Walker, P. 2002. How sustainable agriculture can address the environmental and human harms of industrial agriculture. *Environ. Health. Perspect.* 110(5):445-456.

Human Exposure to Environmental Chemicals, Fourth Report, Updated Tables. 2017. Centers for Disease Control and Prevention. Atlanta, GA: U.S. Department of Health and Human Services, Centres for Disease Control and Prevention.

Koutros, S., Silverman, D.T., Alavanja, M.C., Andreotti, G., Lerro, C.C., Heltshe, S., Lynch, C.F., Sandler, D.P., Blair, A., Beane Freeman, L.E. 2015. Occupational exposure to pesticides and bladder cancer risk. *Int. J. Epidemiol.*, 45(3): 792-805. Available online at: https://dx.doi.org/10.1093/ije/dyv195.

Litchfield M.H. 2005. Estimates of acute pesticide poisoning in agricultural workers in less developed countries. *Toxicol. Rev.*, 24: 217-278.

Mandrich L. 2014. Endocrine disrupters: The hazards for human health. *Cloning & Trans-genesis*, 3: 1.

Menon, R. 2007. Are we being slow poisoned- Health and fitness. https://www.boloji.com/health/articles/01054.htm.

Mesange R., and Seralini G. E. 2018. Editorial: Toxicity of Pesticides on Health and Environment. *Front. Public Health*. 6:268. doi: 10.3389/fpubh.2018.00268.

Mesnage R. and Antoniou M. N. 2018. Ignoring adjuvant toxicity falsifies the safety profile of commercial pesticides. *Front. Public Health*. 5: 361. Available online at: https://doi.org/10.3389/fpubh.2017.00361.

Mullin C.A, Fine J.D, Reynolds R.D and Frazier M.T. 2016. Toxicological risks of agrochemical spray adjuvants: organosilicone surfactants may not be safe. *Front. Public Health*. 4:92. https://doi.org/10.3389/fpubh.2016.00092.

Pesticide Action Network Asia Pacific. Global Governance of Hazardous Pesticides to Protect Children: Beyond 2020', P.A.N.A.P., Penang, Malaysia, January 2017. Available online at: http://panap.net/2017/02/global-governance-hazardous pesticides-protect-children-beyond-2020.

Polyxeni N. S., Sotirios M., Chrysanthi K., Panagiotis S. and Luc H. 2016. Chemical Pesticides and Human Health: The urgent need for a new concept in Agriculture. *Front. Public Health*, 4: 146. https://doi.org/10.3389/fpubh.2016.00148

Roberts, James R. and Catherine J. K. 2012. Technical Report: Pesticide exposure in Children. *Pediatrics.* 130(6): e1765-e1788.

Samanic, C.M., De Roos, A.J., Stewart, P.A., Rajaraman, P., Waters, M.A. and Inskip, P.D. 2008. Occupational exposure to pesticides and risk of adult brain tumors. *Am. J. Epidemiol.*, 167 (8): 976-985.

Sharma N. and Singhvi R. 2017. Effects of chemical Fertilizers and Pesticides on Human Health and Environment: A Review. *I.J.A.E.B.*, 10(6): 675-679.

Virgina, R., Srikesh, A., Megan, H., Frederica, P., Lori, H., Dana, B.B. and Robin, W. 2011. Seven-Year Neurodevelopmental Scores and Prenatal Exposure to Chlorpyrifos, a Common Agricultural Pesticide. *Environ. Health Perspect.*, 119(8): 1196-1201.

Watts and Meriel. 2013. Poisoning Our Future: Children and pesticides, Pesticide Action Network Asia and the Pacific, Penang, Malaysia, p: 58. Available at: <www. India environment portal.org.in/content/385226/poisoning-our-future-children-and pesticides.

Wesseling C., Mc Connell R., Partanen T. and Hogstedt C. 1997. Agricultural pesticide use in developing countries: health effects and research needs. *Int. J. Health Serv.,* 27: 273-308.https://doi.org/ 10.2190/E259-N3AH-TA1Y-H591.

Williamson, Stephanie, Andrew B., and Jules P. 2008. Trends in Pesticide use and drivers for safer pest management in four African countries. *Crop Prot.*, 27(10): 1327-1334. Available at: <www.researchgate.net/publication/248416660_Trends_in_Pesticide_Use_and_Drivers_for_Safer_Pest_Management_in_Four_African_Countries>.

Zheng, S., Chen, B., Qiu, X., Chen, M., Ma. Z., and Yu, X. 2015. Distribution and risk assessment of 82 pesticides in Jiulong River and estuary. Chemosphere, 144: 1177-1192. doi:10.1016/j.chemosphere.2015.09.050.

Chapter - 5

Pesticides and its Classification

C.G. Sawant and S.S. Shinde

Introduction

Agriculture plays a vital role in the Indian economy. In total, food grain production is near about 18 % loss caused due to plant pathogens, pests, weeds, and rodents. To reduce such losses various chemical as pesticides are used enormously. *Pesticide may be defined as any substance or mixture intended for preventing, destroying, repelling, or mitigating any pest and any substance or mixture intended for use as a plant regulator, defoliant, or desiccant*.

It is the broad term under which the Insecticides (which control Insect), Herbicides (which control weed), Fungicides which control fungus) and Rodenticides (which control rats or rodents). Among these insecticides are of chemical or biological origin that controls the Insect. Insecticides are either natural or synthesized and are applied to target pests in a number of formulations (Soiled, liquid, and gaseous form) with the help of appliances such as sprayers, duster, fogger, aerosol, smoke generators, and other devices to the obtained desirable effect of pesticides.

Classification of Pesticides

Based on their use variety of pesticides designed to kill specific pests are listed below.

A. Based on their use or target pests

1. **Acaricides :** The substances used to kill mites and ticks or disrupt their growth or development. E.g., DDT, dicofol, Fenpyroximate
2. **Antifeedants :** The chemicals which prevent an insect or other pest from feeding. E.g., Chlordimeforn, Fentin and Azadirachtin.

3. **Bactericides :** The compounds which are used to kill or inhibit bacteria in plants or soil. E.g., Copper hydroxide, Kasugamycin, Streptomycin, Tetracycline.

4. **Fungicides :** The chemicals which are used to prevent, cure eradicate the fungi. E.g., carbendazim , thiabendazole, thiophanate-methyl.

5. **Chemosterillant :** The chemicals that render an insect infertile and thus prevent it from reproducing. The chemosterilant acts by inhibiting the production of the egg cause the death of the eggs or cause lethal mutation on the spam or eggs material, E.g., Aziridinyl, Diflubenzuron

6. **Herbicides :** Substances that are used to kill plants or to inhibit their growth or development. E.g., Paraquat, Glyphosate, 2,4-D.

7. **Insecticides :** A pesticide that is used to kill insects or to disrupt their growth or development. E.g., Monocrotophos, Carbofuran, Lambdacyhalothrin.

8. **Nematicides :** The chemicals which are used to control nematodes. E.g., Dazomet, fenamiphos.

9. **Plant growth regulators :** The substances that alter plants' expected growth, flowering, or reproduction rate. E.g., NAA, Ethephon

10. **Rodenticides :** The substances used to kill rats and related animals.

11. **Nematicides :** Zinc Phosphide, Bromadiolone.

12. **Avicides :** Chemicals used to repel birds or avians such as anthraquinones, Strychnine, DPTH, Chloralose, Avitrol, etc.

13. **Molluscicides :** A chemical that is used to control snail and slugs such as metaldehyde.

14. **Fumigants :** Fumigants are pesticides that exist as a gas or a vapor at room temperature and may be used as insecticides, fungicides, or rodenticides, especially in closed storage places, as they kill every living organism due to their physical properties, rapid environmental dissemination, and human or animal absorption. E.g., Cyanide, aluminum phosphate, and methyl bromide.

B. Based on mode of entry

1. Stomach poisons

The insecticide which enters the body of the target insect through food is called stomach poison. The insecticides applied on the leaves and other parts of the plants, when ingested, act on the digestive tract of the Insect and bring about kill. These insecticides are very effective against biting and chewing insects. Some of the stomach poisons are toxins produced by the bacteria *Bacillus thuringiensis* and rodenticides such as Zinc Phosphide.

2. Contact poisons

This insecticide enters the body of insects by penetrating through their cuticle or spiracles. The pest may absorb the poison while walking on the treated surface, flying through a mist or fine droplets, or coming in contact directly during spraying or dusting the insecticide. E.g., Fenvalerate, Dimethoate.

3. Fumigants

Fumigants are gaseous pesticides that control pests in agricultural fields, structures like buildings and apartments, storage houses, and other sites. Fumigants are generally volatile with good penetrating power. Aluminum Phosphide, methyl bromide, chloropicrin, and iodoform are some of the most famous examples of fumigants. Some of the chemicals have fumigant action apart from either of the above properties, for instance, DDVP, Lindane, chlorpyrifos.

4. Systemic poisons

Systemic insecticides are when the active ingredient is taken up, primarily by plant roots, and transported (translocated) to locations throughout the plant, such as growing points, where it can affect plant-feeding pests. Systemics move within the vascular tissues, either through the xylem (water-conducting tissue) or the phloem (food conducting tissue), depending on the characteristics of the material. Systemic insecticides are most effective on insects with piercing and sucking mouthparts, such as aphids, whiteflies, mealybugs, and soft scales because these insects feed within the vascular plant tissues. Eg. monocrotophos, carbofuran.

5. Translaminar

These materials penetrate leaf tissues and form a reservoir of active ingredients within the leaf. This provides residual activity against certain foliar-feeding insects and mites.

Insecticides/miticides with translaminar properties include abamectin, pyriproxyfen, chlorfenapyr, spinosad, and acephate. In general, these types of materials are active against spider mites and leafminers. Because the active ingredient can move through plant tissues (that is, leaves), thorough spray coverage is less critical when using these materials to control spider mites, which generally feed on leaf undersides.

C. Based on mode of action

1. Physical poisons

Poisons that kill the Insect by exerting a physical effect are known as physical poisons. Heavy oils and tar oils kill the insects through asphyxiation, i.e., exclusion of air. Inert dust causes abrasion of cuticle or absorbs moisture from the body of the Insect. Ultimately insects get die due to loss of moisture.

2. Protoplasmic poisons

The toxicants that kill the Insect by destroying the cellular protoplasm of the mid-gut epithelium are called protoplasmic poisons. Mercury, Copper, and arsenic compounds are an example of this group.

3. Respiratory poisons

Poisons that inhibit cellular respiration and render the respiratory enzymes inactive are termed respiratory poisons, e.g., HCN, CO, etc.

4. Nerve poisons

Poisons that affect the nervous system and render the Insect behave abnormally, leading to death, are called nerve poison. These chemicals solubilize in tissue lipid and inhibit acetylcholinesterase enzyme activity in insects and mammals. E.g., Organophosphate and carbamate insecticides.

5. Chitin inhibitors

These chemicals affect the enzyme chitin synthetase during chitin formation and inhibit chitin synthesis. E.g., Diflubenzuron.

D. Based on the chemical nature

Based on the molecular structure, the pesticides are divided into two groups: inorganic and organic.

1. Inorganic insecticides

a. Arsenicals

Classification based on toxicity

Classification of the insecticides	Oral LD50 mg/kg body weight of test animals	Dermal LD50 mg/kg body weight of test animals	Colour code on the label	Symbol
Extremely toxic	1-50	1-200	Bright red	
Highly toxic	51-500	201-2000	Bright yellow	
Moderately toxic	501-5000	2001-20000	Bright blue	
Slightly toxic	More than 5000	More than 20000	Bright green	

(Insecticide rule 1971)

i. Lead arsenate

There are two types of lead arsenate, i.e., acid orthoarsenate and basic orthoarsenate. The acid form is more effective and widely used against beetles and insects having the chewing type of mouthparts.

ii. Calcium arsenate

It is a white powder. It is a stomach poison and is very effective against leaf-eating insects.

b. Fluorine compounds

These are used in baits against chewing insects and household pests. E.g., Sodium fluoride and sodium fluoaluminate.

c. Other inorganic compounds

It includes sulfur, lime sulfur, barium carbonate, thallium sulfate, and zinc phosphide.

2. Organic insecticides

A. Hydrocarbon oils

The constituents of the oils are the sole of hydrogen and carbon. Two groups viz., mineral (petroleum) oils and coal- tar oils, are recognized under hydrocarbon oils. Kerosene, diesel, crude oil, and pine oils are used against household and orchard pests. The soaps are used as wetting agents, stabilizers, and spreaders.

B. Insecticides of animal origin

This toxicant knew to as nereistoxin (4-N, N- dimethylamino)-1, 2-dithiolane). A toxin isolated from the marine annelids *Lumbrineris* (*Lumbriconeris*) *heteropoda* and *L. brevicirra* has been found to possess insecticidal properties. These are effective against coleopteran and lepidopteran pests. It interacts with nicotinic acetylcholine receptors, i.e., they are pro-insecticides. Eg. cartap, bensultap and thioclam.

C. Insecticides of plant origin

These toxicants derived from plants are used as baits in insect and nematode control, insect attractants and repellents, and diluents in insecticidal formulations.

i. Nicotine

Nicotine is the principal alkaloid found in the leaves of *Nicotiana tabacum* and *N. rustica* from 2 to 14 % and also in *Duboisiahopwoodii* and *Asclepias syriaca.* Its molecular name and empirical formulae are $C_{10}H_{14}N_2$ and Nicotine-1, 3-(I-Methylpyrrolidyl) pyridine. It is a nerve poison and mimics acetylcholine in the nerve synapse, causing tremors, loss of coordination, and eventually death. It is extremely fast-acting, causing severe disruption and failure of the nervous system. It is commercially sold as a fumigant (Nicotine) or as dist (Nicotine sulphate). It is commercially available as Nicotine sulphate 40% (Black leaf 40) and manufactured in India only for export purposes. It is contact poison effective against soft-bodied or sucking insects like thrips, leafhoppers, mealybugs, and leaf miners.

ii. Pyrethrins

Pyrethrins are obtained from flowers of *Chrysanthemum cinerariaefolium*, *Chrysanthemum coccineum*, and *C. Carneum*. Pyrethrins are all toxic constituents of the pyrethrum flower, and pyrethroid is the synthetic analogue of pyrethrins. Its molecular name and empirical formula is $C_{21}H_{28}O_3$ and 5-methyl-4-oxo-3-penta-2,4-dienylcyclopent-2-en-1-yl 2,2-dimethyl-3-(2-methylprop-1-enyl) cyclopropane-1-carboxylate, respectively. The six constituents of pyrethrins are pyrethrin I and II, cinerin I and II, and jasmolin I and II. They are collectively known as pyrethrins, which are the esters of two carboxylic acids, chrysanthemic and pyrethric acid. The insecticidal properties are attributed to five esters except jasmoline I which are predominantly found in achenes of flowers from 0.7 to as much as 3 %. The esters are derived from two acids (chrysanthemic acid and pyrethric acid) and alcohol cinerolone, pyrethrolone, and jasmololone. The esters containing pyrethrolone are called pyrethrina I, if the acid is chrysanthemic acid, and pyrethric II, if the acid is pyrethic acid. Similarly, those containing cinerolone are called cinerins I, if the acid is chrysanthemic acid, and cinerin II if the acid is pyrethric acid. It is a powerful contact insecticide but a poor stomach poison. The mode of action is similar to DDT and fast knockdown effect and shows rapid recovery due to rapid enzymatic detoxification in the Insect. It breaks down quickly from sunlight. They are commonly used with a synergist such as piperonyl butoxide, propyl isome, and sulfoxide. This synergist is used at 10 parts to 100 parts of the pyrethroid. It is used as a repellent against external parasites of livestock and control store grain pests.

iii. Rotenone

It is a resin derived from roots and seeds of leguminous plants *Lonchocarpus* spp (South American plant), which contains (8-11 %) and *Derris elliptica* (Malaysia) (4-9 %). Its molecular name and empirical formula is $C_{23}H_{22}O_6$ and (2R,6aS,12aS)-8,9-Dimethoxy-2-(prop-1-en-2-yl)-1,2,12,12a-tetrahydro [1] benzopyrano [3,4-b] furo [2,3-h] [1] benzopyran-6 (6aH)-one, respectively. It has broad-spectrum contact and stomach poison. It affects nerve and muscle cells in insects and sometimes causes the Insect to stop feeding. It inhibits respiratory metabolism and is highly toxic to fish. Use as dust 0.75-1.5 % rotenone and effective against beetle and caterpillar.

iv. Sabadilla

It is an alkaloid obtained from seeds of tropical Lily *Schoenocaulon Officinale* (Family:

Liliaceae) (2-4%). Its empirical formula is $C_{68}H_{100}N_2O_{20}$. Cevadine and veratridine are insecticidal components and act primarily as a contact poison, nerve poison, and toxic to pollinators and honey bees. It is used for the control of house flies and domestic insects.

v. Ryania

This alkaloid is derived from woody stems of South American shrub, *Ryania speciosa* (Family: Flacourtaceae). It is a slow-acting stomach poison and causes the Insect to stop feeding. It is a muscular poison that generally blocks ADP to ATP conversion in striated muscles. A methylpyrrole-carboxylate from ryania disrupts the Ryanodine Receptor Calcium Release Channel to modify calcium release from Sarcoplasmic Reticulum, resulting in alteration of muscle contraction. It was previously used in insecticides. It is used experimentally in conjunction with Thapsigargin and other calcium atpase uptake inhibitors into the sarcoplasmic reticulum. Its molecular name and empirical formula is $C_{25}H_{35}NO_9$ and [(1R, 2R, 3S, 6S, 7S, 9S, 10S, 11S, 12R, 13S, 14R)-2, 6, 9, 11, 13, 14-hexahydroxy-3, 7, 10-trimethyl-11-propan-2-yl-15 oxapentacyclo [7.5.1.01, 6. 07, 13. 010, 14] pentadecan-12-yl] 1H-pyrrole-2-carboxylate, respectively. It is used as dust (20-40 %) and is effective against thrips and worms.

vi. Neem (*Azadirachtia indica*)

Neem is native of India and Burma. Neem, along with the various species of the Meliaceae family, namely, *Azadirachta indica* has emerged as the top botanical insecticide with the highest potential. The Meliaceae mainly, *A. indica* (Indian neem tree), contains at least 35 biologically active principles, of which Nimbin and Azadirachtin are the most active insecticidal ingredients. The main potential active ingredient showing insecticidal activity is Azadirachtin (AZA), a ring C-secotetranortriterpenoid, is the most potent natural insect antifeedant discovered, which presents in seeds and leaves and it varies from 2-4 mg/g kernel. The active ingredient is a mixture of Azadirachtin, melantriol, salannin, nimbin, and nimbidin, and these all belong to a group of tetranortriterpenoids (limonoids). It has seven types of stereoisomers. Azadirachtin A constitutes 85 %, followed by Azadirachtin B almost 14 %. It has antifeedant action, Insect growth regulatory activity inhibits juvenile hormone synthesis, ovipositional deterrent, repellent action, reduction of the life span of adults and intermediate are formed to give larval-pupal, nymphal-adults and pupal-adult intermediates. Neem is commercially available as Need Seed Kernel Extract (NSKE) and Neem oil having different parts per million concentrations in the market.

D. Synthetic organic insecticides

Synthetic organic insecticides are relatively new compounds. It is a group of pesticides chemically synthesized or formulated to kill insects. Today, these are proved a major important group to control the insect pests in the field. The first synthetic organic insecticide was DDT synthesized in 1874, and its insecticidal properties were first recognized in 1939.

a. Organic metal insecticides

ii. Paris green

iii. Phenolic compound

b. Organic thiocyanates

c. Organochlorine insecticides

The primary constituents of organochlorine compounds are carbon, hydrogen, and chlorine, and specific compounds may have oxygen and sulphur also.

i. DDT

ii. Dicofol

iii. HCH

iv. Lindane

d. Cyclodiene insecticides

i. Endosulfan

e. Organophosphorous insecticides

These are esters of phosphoric and phosphorothioic acids. These consist of phosphorous, carbon, nitrogen, oxygen, and sulphur. These insecticides are considered derivatives of corresponding acids. W. Lange and Gerda V. Krueger, in 1932 discovered the biological activity of the organophosphorus esters. Practically this insecticide developed mainly due to the work of Gerhard Schrader and his associates beginning in 1937. He developed tetraethylpyrophosphate (TEPP) as a substitute for nicotine. A further search for a stable lime compound led to the development of parathion, followed by Schradan, the first practical systemic insecticide. Organophosphorous compounds can kill by contact, systemic or fumigant action, or a combination of the three. They affect the nervous system by disrupting an enzyme that regulates acetylcholine, a neurotransmitter—a nerve poison that can cause acute toxic reactions in humans.

i. Organophosphates

1. Dichlorvos (DDVP)
2. Monocrotophos
3. Phosphamidon

ii. Organothiophosphates

1. Phenthoate

iii. Aliphatic organothiophosphates

1. Ethion
2. Malathion
3. Oxydemeton methyl
4. Phorate
5. Thiometon

iv. Aliphatic amide thiophosphates

1. Dimethoate

v. Heterocyclic organothiophosphates

1. Phosalone

vi. Pyridine organothiophosphates

1. Chlorpyrifos
2. Chlorpyrifos-Methyl

vii. Pyrimidine organothiophosphates

1. Diazinon
2. Pirmiphos-methyl

viii. Quinoxaline organothiophosphates

1. Quinalphos

ix. Triazole organothiophosphates

1. Triazophos

x. Phenyl organothiophosphates

1. Fenitrothion
2. Fenthion
3. Methyl parathion
4. Profenofos
5. Temephos

xi. Phosphonates

1. Trichorfon

xii. Phosphoramidothioates

1. Acephate
2. Propetamphos

f. Carbamate insecticides

In general, carbamates insecticides are synthetic derivatives of physostigmine commonly called "Eserine," which principal alkaloid from seeds of the plant Calabar beans, *Physotigmavenenosum*. These are derivatives of carbamic acid and dithio carbamic acid. They have systemic and contact in action. They are nerve poisons and inhibit acetylcholinesterase activity at synapse or nerve junctions. They act similar to organophosphorus compounds except for the reversible nature of toxicity. Physostigmine is unsuitable as insecticides as they are too polar and unable to penetrate the insect cuticle. Modern insecticides belongings to carbamates are modified by eliminating the polar moiety so that they can effectively penetrate the insect cuticle. Carbamate insecticides are the derivatives of carbamic acid and dithio-carbamic acid. The key features for activity in insecticidal carbamates are their structural resemblance to acetylcholine cholinesterases and thus have a high affinity for enzyme cholinesterases. Carbamates show pronounced synergist if piperonyl butoxide or sesoxane, or propyl isome is added. They rapidly metabolize and, in mammals, excrete in the urine.

i. Phenyl carbamates

1. Bendiocarb
2. Carbaryl

ii. Benzofuranyl methyl carbamates

1. Benfuracarb
2. Carbofuran
3. Carbosulfan

iii. Oxime carbamates

1. Methomyl
2. Thiodicarb

iv. Phenyl methyl carbamates

1. Fenobucarb or BPMC
2. Propoxur

v. Dithiocarbamate

1. Dazomet

g. Organic sulphur compounds

i. Sulfides

ii. Sulfones

h. Synthetic pyrethroids

These are the groups of pesticides primarily derived from dried Chrysanthemum flowers, a natural source of pyrethrins or pyrethrum. They are chemically synthesized for their more toxicity, quick knockdown effect, and photostability under sunlight. They are formulated with synergists that help to increase potency and are easily detoxifyable. Many pyrethroids have been linked to disrupting the endocrine system, reproduction, sexual development, interference with the immune system, and breast cancer induction (Thatheyus and Deborah,2013). It acts as nerve poison and strongly modulates the Sodium channel gate in the nerve synapse. The widespread use of synthetic pyrethroids is a serious concern. They are responsible for the resurgence of minor pests, pollute agricultural lands and water bodies, proved toxicity to fishes, and affect non-target organisms like predators, parasitoids, etc. (Thatheyus and Deborah, 2013).

i. Allethrin

ii. d-Allethrin

iii. Trans Allethrin

iv. S-Bioallethrin

v. Cyfluthurin

vi. Beta-cyfluthrin

vii. Lambda-cyhalothrin

viii. Cypermethrin

ix. Alpha cypermethrin

x. Deltamethrin

xi. Imiprothrin

xii. Bifenthrin

xiii. Cyphenothrin

xiv. Fenpropathrin

xv. Fenvalerate

xvi. Permethrin

xvii. Prallethrin

xviii. Transfluthrin

xix. Etofenprox

i. Other groups of organic insecticides

i. Neo-nicotinoids

Neonicotinoids are a new class of insecticides chemically related to nicotine. It is a synthetic analog of nicotine. The name means “new nicotine-like insecticides.” Like nicotine, neonicotinoids act on certain kinds of Nicotinic acetylcholine receptor (nAChR) in the nerve synapse. They are much more toxic to invertebrates, like insects, than mammals, birds, and other higher organisms. One thing that has made neonicotinoid insecticides popular in pest control is their water solubility, which allows them to be applied to soil and be taken up by plants. Soil insecticide applications reduce the risks for insecticide drift from the target site and at least some beneficial insects on plants.

1. Chloronicotinyl compounds

These are the inhibitors of the nicotinic acetylcholine receptors, which are present in an insect's nervous system. Before introducing these compounds, the target over acetylcholine receptor was represented by nicotine itself or nereistoxin analogs without any real commercial relevance. The introduction of the first chloronicotinyl insecticide, imidacloprid, by Bayer at the beginning of the 1990s met that demand, culminating in a tremendous economic success (Detlef and Klaus, 1999).

- Imidacloprid
- Acetamiprid

2. Thionicotinyl group compounds

Insecticides of this group are broad-spectrum, having quick systematic and contact activity, absorbed quickly by plants, and transported to all of its parts, including pollen, where it acts to deter insect feeding. These compounds are used against many Insects especially sucking pests. It can absorb in the stomach after feeding, or through direct contact, including its tracheal system. The compounds get in the way of information transfer between nerve cells by interfering with nicotinic acetylcholine receptors in the central nervous system and eventually paralyzing the insects' muscles (FAO. 2000).

- Thiamethoxam
- Clothianidin
- Thiacloprid

3. Phenyl pyrazoles

The insecticides of this group have a systemic compound with contact and stomach activity. It blocks the gamma-aminobutyric acid (GABA) regulated chloride channel in neurons, thus antagonizing the "calming" effect of GABA (Gavkare *et al.*, 2013). This group is effective against stem borer, gall midge, DBM, thrips, shoe borers, root borer and can be used in crops viz., sugarcane, cruciferous crops, cotton, and rice.

- » Fipronil
- » Ethiprole

4. Pyridine azomethines

The insecticide of this group has no direct toxicity against insects but it blocks stylet penetration of sucking insects which may cause immediate cessation of feeding after exposure to this insecticide (Gavkare *et al*., 2013). It is effective against sucking pests.

- » Pymeteozine

5. Oxadiazine group

The insecticide of this group inhibits the flow of sodium ions into nerve cells in insects that cause paralysis and death and enter into the insect body in two ways: through ingestion of treated foliage, and another one is penetration through insect cuticle (Gavkare *et al*., 2013). It effectively controls a variety of Lepidoptera pests, especially against American bollworm, Helicoverpa armigera, and diamondback moth (DBM).

- » Indoxacarb

6. Halogenated pyrroles

It acts by disrupting the proton gradient across the mitochondrial membrane and preventing mitochondria from producing ATPs (Gavkare *et al*., 2013). It is found effective against DBM in cabbage and cauliflower and also against mites in chili.

- » Chlorfenapyr

7. Thiazolidine group

This group act as an acaricide. It affects the growth and development of mites and is used to control red spiders and yellow mites in tea and chili (Gavkare *et al*., 2013).

- » Hexythiazox

8. Thiourea derivatives

This insecticide inhibits oxidative phosphorylation, i.e., specifically, they inhibit ATP synthase (Gavkare *et al*., 2013). They are found to be effective against sucking insects.

- » Diafenthiuron

9. Sulfide ester group

It inhibits oxidative phosphorylation, i.e., this compound act as a disruptor of ATP formation (Gavkare *et al*., 2013). It is highly effective against phytophagous mites in various crops.

» Propargite

10. Diamide group

This group possesses a unique chemical structure. It modulates the ryanodine receptors, which are intracellular Ca2+ channels specialized for the rapid and massive release of Ca2+ from intra cellular stores, essential in the muscle contraction process (Gavkare *et al*., 2013) because the depletion of calcium causes paralysis and the death of insects.

» Flubendiamide

» Chlorantraniliprole

» Cynrantraniliprole

11. Tetronic acid derivatives

Insecticides of this group block the fat synthesis, which ultimately causes the target pest to dry out and die, i.e., the active ingredient is a lipid biosynthesis inhibitor that prevents insects from maintaining a necessary water balance (Gavkare *et al*., 2013).

» Spiromesifen

12. Quonazoline group

It inhibits mitochondrial electron transport chain by binding with complex I at co-enzymes site Q (Gavkare *et al*., 2013). It is also an acaricide group of insecticides that proved effective against mites in tea and chili.

» Fenazaquin

13. Pyridalyl

Active ingredients of this group are of an unknown or uncertain mode of action.

14. Diacyl hydrazine insecticides

These are ecdysone receptor agonists, which regulate the growth and development of insects in their various stages.

- Chromafenozide
- Flonicamid
- Halofenozide,
- Methoxyfenozide
- Tebufenozide

15. Organofluorine pesticide

This group belongs to acaricide and herbicide used worldwide since 1998. Organofluorine pesticides may well prove to be as toxic or more toxic than chlorinated pesticides. This is an alternative for carbamates, organochlorines, and other miticides. It disrupts normal cellular physiology and might cause early implantation failure in mammals and Insects too. It might cause implantation failure via growth retardation and induction of cell death in porcine trophectoderm and endometrial luminal epithelium (Park *et al.*, 2020).

- Etoxazole

16. Six membered heterocyclic compounds

Heterocyclic compounds are found abundantly in plants and animal products, and they are one of the vital constituents of almost one-half of the natural organic compounds known. These compounds are anticoagulant rodenticides and are absorbed through the digestive tract, the lungs, or skin contact. These are generally applied orally in the form of single-dose poison bait or cake form. Multiple doses are also required for rodenticide belonging to this group. The substances are vitamin K antagonists. The lack of vitamin K in the circulatory system reduces blood clotting and will cause death due to internal hemorrhaging (FAO, 1996). Heterocyclic compounds have a wide application in pharmaceuticals, agrochemicals, and veterinary products (FAO, 1996).

- Bromadiolone
- Coumatetralyl
- Coumachlor

j. Insecticides from microbes fermentation

i. Avermectins

Sixteen membered macrocyclic lactones derived or isolated from mycelia of actinomycetes, a soil-dwelling bacteria, Streptomyces avermitilis. It is a crude fermented product that contains eight analogs, of which avermectin B1a & B1b) were in higher concentration. It blocks the transmission of electrical activity in invertebrate nerve and muscle cells primarily by enhancing the effects of glutamate at the glutamate-gated chloride channel that is specific to protostome invertebrates (Wolstenholme, 2012), with minor effects on gamma-aminobutyric acid receptors (Cully *et al.*, 1994, Bloomquist, 1996; Bloomquist 2003). This causes an influx of chloride ions into the cells, leads to hyperpolarisation and subsequent paralysis of invertebrate neuromuscular systems; comparable doses are not toxic for mammals because they do not possess protostome-specific glutamate-gated chloride channels (Bloomquist, 1993; Wolstenholme, 2012).

1. Abamectin

It is a member of the Avermectin family and is a natural fermentation product of soil-dwelling actinomycete, Streptomyces avermitilis. It is used against sucking pests, dipterans, Psyllidae, leaf miner, and phytophagous mites and is also used to control the parasites of cattle. It is not registered under u/s 9(3) the Insecticide Act.

2. Emamectin benzoate

It is generally prepared as salt with benzoic acid emamectin benzoate, a white or faintly yellow powder. It is a derivative of avermectin B1. It is widely used against bollworms on cotton, thrips, flea beetle, mites in grapes, diamondback moth in cabbage and brinjal shoot, and fruit borer in brinjal. The available formulation is 5 S.G.

ii. Spinosyns

It is a novel action insecticide derived from a family of natural products obtained by fermentation of *Saccharopolyspora spinosa*. It occurs in over 20 natural forms, and over 200 synthetic forms (spinosoids) have been produced in the lab (Watson, 2001). By both contact and ingestion, it is highly active in numerous insect species (Hertlein *et al.*, 2011) Its overall protective effect varies with insect species and life stage. It affects certain species only in the adult stage but can affect other species at more than one life stage. The formulation of spinosyns a.i. Spinosad is a mixture of the two most active metabolites, Spinosyn A and spinosyn D, roughly in the ratio of 17:3 (Mertz and Raymond, 1990). The first spinosad product 'Tracer' and 'Conserves' launched in the USA. It is a neurotoxin where Spinosyns D acts on nicotine acetylcholine receptors, whereas only Spinosyns A alters the function of GABA gated chloride channels. Highly effective against Insect from orders Lepidopterous, Dipterans, Thysanoptera, and few Coleopterans.

iii. Milbemycins

Unlike avermectins, milbemycins are also a product of fermentation by *Streptomyces* species. These are a mixture of milbemycin Aa and milbemycin A4 in the ratio of 3:7. They have a longer half-life than the avermectins. It is a GABA antagonist that enhances the binding of GABA and increases chloride flow. They open glutamate-sensitive chloride channels in neurons and myocytes of invertebrates, leading to hyperpolarisation of these cells and blocking signal transfer (Toranmal *et al.*, 2019). It is available in 1 % E.C. formulation. It is effective against spiders and mites in chili.

iv. Acetaldehyde polymer

1. Metaldehyde

It is a molluscicide commonly used against slugs, snails, and other gastropods, especially in vegetable crops. It is used as 2.5 % dust. It can prove fatal to dogs and cats.

k. Insect growth regulators (IGRs)

i. Benzoyl phenyl ureas (BPUs)

BPUs are chemical derivates of urea and are classified as inhibitors of chitin synthesis. It has a property to interfere with chitin depositions in the endocuticle, which results in abnormal development of the moulting process in many larvae of different insect orders.

1. Buprofezin

Buprofezin is an insecticide used to control insect pests such as mealybugs, leafhoppers, and whiteflies on vegetable crops. It is a growth regulator, acting as a stomach and contact poison that inhibits chitin synthesis. It is banned in some countries due to its negative environmental impacts, being incredibly toxic to aquatic organisms and non-target insects. However, it is of low toxicity to humans and other mammals. It is formulated as 25 % S.C.

2. Diafenthiuron

It acts as an insecticide and acaricide by contact, stomach, and ovicidal action. It controls whiteflies and other sucking pests and mites in various crops, especially cotton, chili, brinjal, and cardamom. The available formulation is 50 % W.P.

3. Diflubenzuron and teflubenzuron

Diflubenzuron and Teflubenzuron are insecticides that act as growth regulators by inhibiting chitin synthesis, the main component of the exoskeleton of crustacean ectoparasites. It is highly insoluble in water and has to be ingested to be effective. It is not systemic in plants and therefore does not work on sap-sucking insects. Although one would expect that it should be effective on all open feeding lepidopteran larvae, it is not uniformly effective, and this could be due to detoxification in some species (Jin, 2014). It is effective against cotton bollworms, groundnut leaf folder, and Spodoptera larvae. It is sold under the Dimilin trade name. The available formulation is 25 % W.P.

4. Flufenoxuron

It is a broad-spectrum chitin synthesis inhibitor effective against DBM and rose mite. It is sold under the Cascade trade name. The available formulation is 10 % D.C.

5. Novaluron

It is insecticide/miticide effective against DBM on cabbage, tomato, chili fruit borer, cotton bollworm, and gram pod borer. The available formulation is 10 % E.C., and Rimon is a trading name.

6. Hexythiazox

It has the distinction of being the first IGR Acaricide to be introduced in India. It has novel acaricidal chemistry with excellent ovicidal, larvicidal, and nymphicidal properties, which controls phytophagous mites of different species in different crops. The available formulation is 5.45 % E.C. and sold under Maiden trading name.

7. Lufenuron

It is effective against diamondback moth on cabbage, tomato, chili fruit borer, cotton bollworm, and gram pod borer. The available formulation is 5.4 % E.C., and Match is a trading name.

ii. Juvenile hormone mimic

Juvenile hormone analogs and mimics juvenile hormone when applied to an insect, an abnormally high level of juvenilizing agent will produce another larval stage or produce larval-pupal intermediates. Juvenoids IGRs can also act on eggs, can cause sterilization, disrupt behavior and disrupt diapauses. Anti-juvenile hormone agents cancel the effect of juvenile hormone, early instars treated with an anti-juvenile hormone moult prematurely into a nonfunctional adult—Ex., methoprene, kinoprene, hydroprene, pyriproxyfen, fenoxycarb, etc. Examples of ecdysteroids include compounds, namely tebufenozide (MIMIC, CONFIRM), halofenozide, methoxyfenozide, chromafenozide, difenolan, etc.

l. Fumigants

Fumigants are essential in pest management programs because of their unique ability to diffuse throughout common airspace in a commodity, substrate, or structure to eliminate a broad range of pests. It is practically used under situations wherein other insecticides either penetrate with difficulty or are not used. In this respect, the diffusion rate of fumigant is of significance. Many fumigants are used to treat the soil to be cultivated to control insects, fungi, nematodes, and weeds. Fumigants with high vapour pressure are used to treat stored grains or materials enclosed in gasproof structures. Low-pressure compounds such as ethylene dibromide and ethylene dichloride diffuse more slowly; they are used to treat more open storage areas and as soil fumigants (Britannica, 2019). Fumigants used to treat stored products or nursery stock include hydrogen cyanide, naphthalene, nicotine, and methyl bromide. Soil fumigants commonly used as nematocides are methyl bromide, dichloropropane, propylene oxide, dibromochloropropane, organophosphate insecticides, and chloropicrin (Britannica, 2019). Because these substances may kill other soil organisms that ordinarily control nematodes by predation or infection, severe nematode infestations may follow fumigation (Britannica, 2019).

i. Aluminum phosphide or phosphine or hydrogen phosphide

It is highly combustible, so safe and convenient fumigant with a strong garlic smell. It is available in tablet (Celphos) and pellet forms. The composition of Aluminum phosphide is Aluminium phosphide (56 %), Ammonium carbamate (41 %), and paraffin wax (3 %). It is used as a rodenticide, insecticide, and fumigant to kill small verminous mammals such as moles and rodents in stored cereal grains. The tablets or pellets, known as "wheat pills", typically also contain other chemicals that evolve ammonia which helps to reduce the potential for spontaneous ignition or explosion of the phosphine gas. The tablet is 3 grams, releasing 4 Gram of phosphine gas, whereas pellets weigh 0.5 grams and are available in tins containing 16 tubes of 30 tablets. The recommended dose is 3 tablets/tonne of grain or 140 tablets/100m2 areas (David and Ramamurthy, 2017).

ii. Hydrogen cyanide or hydrocyanic acid (HCN)

It is a colorless, extremely poisonous, flammable liquid that boils slightly above room temperature, at 25.6 °C (78.1 °F). It is volatile to be employed as the gas under normal atmospheric pressure and not able to penetrate. It is the globally most extensively used fumigant for the control of cottony cushion scale *Icerya purchasi*. Its efficacy and application method lead to minimal amounts of the fumigant being used compared to other toxic substances used for the same purpose (Bond, 1989). It is released when sodium is treated with sulphuric acid. General fumigation is 10-16 g Na C.N. 98 % pure with 20-30 ml H2SO4 and 40-60 ml of water/m3 (David and Ramamurthy, 2017).

iii. Ethyl bromide or bromomethane

Ethyl bromide appears as a colorless volatile liquid. Slightly soluble in water and denser than water. Vapors are heavier than air. It is toxic by inhalation and irritates skin and eyes. At ordinary room temperature, it releases gas and in containers under pressure as a liquid. The gas is 1.5 times as heavy as air. To control stored grain pests, it is used at a 24-32 g/m3 exposure period of 48 hours. It is effective against termite, powder post beetle, nematodes, rodent, fungi, and weeds in the soil. Add chloropicrin to the cylinder containing methyl bromide (Commercial product Dowdume MC-2 has 2% chloropicrin). It is generally done to detect it because gas, when it persists for a longer time in the area, will irritate the eyes. It may prove dangerous to warm-blooded animals (David and Ramamurthy, 2017).

iv. Chloropicrin or trichloronitromethane

It is used as a broad-spectrum antimicrobial, fungicide, herbicide, insecticide, and nematicide. It is nothing but tear gas having low volatility, which is non-inflammable with an excellent penetrating effect. Its gas persists for a more extended period. It is mainly used to control soil pests but is not recommended for fumigating germinating seeds. It is not recommended for vegetables, fresh crops, and fruits. Its use has not been registered in India (David and Ramamurthy, 2017).

v. Ethylene dichloride

It is a colourless liquid with a chloroform-like odour and gas inflammable between 6 and 16 % in air. It is a slow-acting fumigant as the death of insects occurs 1-3 days after exposure. Generally used with carbon tetrachloride (David and Ramamurthy, 2017).

vi. Ethylene Dichloride Carbon Tetrachloride

Ethylene dichloride liquid and vapors are flammable, and thereof it is mixed with non-flammable fumigant like carbon tetrachloride (CCl4) in the ratio of 3:1. It is used as a fumigant to kill insects pests in storage and soil pests. It is generally used at 24 ^{o}C @160-300 g/M^3 for 24 hours in airtight buildings (David and Ramamurthy, 2017).

vii. D.D. Mixture

It is a mixture of 1,2-dichloropropane, 1,3-dichloropropene and other chlorinated hydrocarbons. It has been used as a soil fumigant nematicide, insecticide, herbicide and fungicide. The 1,2-dichloropropane component was relatively inactive as a nematicide at concentrations used in agricultural fields, and the mixture is now obsolete as a pesticide (CHEBI:142441, 2018). It is the black liquid available as 100 % formulation. One liter of D.D. Mixture cantains one kilogram of technical grade. It is frequently used against soil insect at a depth of 15-20 cm. It can be used as fungicide at very high dose. As it is phytotoxic, it is used for pre-plant soil application (David and Ramamurthy, 2017).

viii.Naphthalene

Naphthalene is a white, volatile, solid polycyclic hydrocarbon with a strong mothball odor that vaporizes slowly. The gas when mixed with air is inflammable. Napthalene balls are used at a dosage of 1 g/m^3 against cloth moths and carpet beetles, in households and museums (David and Ramamurthy, 2017). It is not recommended in grains as it has been withdrawn for its use.

ix. Paradichlorobenzene

It is a fumigant insecticide and repellent used to control clothes moths. Its vapors is toxic to insects. It has been withdrawn for its use.

x. Ethylene dibromide (EDB)

Ethylene dibromide was used as a fumigant to protect against insects, pests, and nematodes in citrus, vegetable, and grain crops, and as a fumigant for turf, particularly on golf courses (ATSDR, 2018). It is currently used in U.S. to treat felled logs for bark beetles and termites, and control of wax moths in beehives in (ATSDR, 2018). It is highly toxic to humans. In india it is banned for its manufacturing, imports and use.

m. Microbial insecticides

Microbial insecticides comprise microscopic living organisms (bacteria, fungi, viruses, protozoa, or nematodes) or the toxins produced by these organisms. They have been mass-produced and formulated for use as insecticides. They are prepared to be applied as conventional insecticidal sprays, dusts, liquid drenches, liquid concentrates, wettable powders, or granules. Each product's specific properties determine the ways in which it can be used most effectively. The followings are some microbial insecticides.

i. Bacterial strains with the available formulations

It is most effective against lepidopterans pests in various crops like Paddy, cotton, gram, caster, pigeon pea, tobacco, soybean, cabbage, okra, tomato, brinjal, etc. (CIB & RC, 2021).

1. *Bacillus thuringiensis* var. *galleriae* 1593 M serotype H 59 5b, 1.3 % flowable concentrate Potency 1500 IU/mg.
2. *Bacillus thuringiensis* var. *4rustaki.*
3. *Bacillus thuringiensis* var. *4rustaki,* serotype H-39, 3B, Strain Z-52.
4. *Bacillus thuringiensis* serovar *4rustaki* (3a, 3b, 3c) 5.0 % WP Potency 55000 SU (*Spodoptra* unit based).
5. *Bacillus thuringiensis* var. *5rustaki* 0.5 % WP serotype *3a, 3b, 3c*, Strain DOR Bt-1, Potency 9000 IU/mg min. U/s 9(3b).
6. *Bacillus thuringiensis* var. *5rustaki* 0.5% WP serotype 3a, 3b, 3c, Strain DOR Bt-1 NAIMCC-B-01118, Potency 13329 IU/mg min. U/s 9(3b).
7. *Bacillus thuringiensis* var. *5rustaki* 0.5 % WP serotype 3a, 3b, 3c, Strain DOR Bt-1, Potency 9000 IU/mg min. U/s 9(3b).
8. *Bacillus thuringiensis* var. *5rustaki* 0.5 % WP serotype 3a, 3b, 3c,Strain DOR Bt-1, Potency 16000 IU/mg min.
9. *Bacillus thuringiensis* var. *5rustaki* 2.5% AS (Spicbio-BTK AS).
10. *Bacillus thuringiensis* var. *5rustaki,* Serotype H-3a, 3b, Strain Z-52.
11. *Bacillus thuringiensis* var. *6rustaki* Strain HD-1, serotype 3a, 3b, 3.5% ES for Import & repack. Potency17600 IU/mg.
12. *Bacillus thuringiensis* var. *6rustaki* Serotype 3a, 3b, SA II WG Potency:- 53000 SU/mg, 32000 IU/mg.
13. *Bacillus thuringiensis* var. *israelensis* WP.
14. *Bacillus thuringiensis* var. *israelensis*, Serotype H-14 (VECTOBAC 12 AS) Potency 1200 ITU / MG (VCRC Serotype H-14 strain.
15. *Bacillus thuringiensis* var. *israelensis*, Serotype H-14 (Vectobac 12 AS) potency 1200 ITU/mg.
16. *Bacillus thuringiensis* var. *israelensis* 5.0 % AS (Strain VCRC-B-17, Serotype H-14, Accession No.- MTCC 5596) potency 630 ITU/mg.min.
17. *Bacillus thuringiensis* var. *israelensis* (H-14) 5.0% AS.

18. *Bacillus thuringiensis* var. *israelensis,* Serotyp H-14, 5% WP Potency 2000 ITU/mg.

19. *Bacillus thuringiensis* var. *israelensis,* Strain Designation- ABIL, Accession No. NAMICC-B01318 (CFU Count- 4.8 x 108) Serotyp H-14, 5% WP Potency 7000 ITU/mg.

20. *Bacillus thuringiensis* var. *Sphaericus* 1593 M sero type H 59 5b.

21. *Bacillus thuringiensis* var. *israelensis* 12 % AS (Vectobac).

22. *Bacillus thuringiensis* var. *israelensis* 00.50 % WP.

23. *Bacillus thuringiensis* var. *israelensis* 05.00 % WP.

24. *Bacillus sphaericus* 1593 M serotype H 59 5b, 1.3 % flowable concentrate Potency 13000 IU/mg.

25. *Pseudomonas fluorescens* 1.0 % WP (Strain No. IIHR-PF-2, Accession No. ITCC- B0034).

ii. Fungal strains with the available formulations

It is most effective against lepidopteran larvae, coleopteran, hemipteran insects, and nematodes in various crops like Paddy, cotton, gram, caster, pigeon pea, tobacco, soybean, cabbage, okra, tomato, brinjal, etc. (CIB & RC, 2021).

1. *Beauveria bassiana* 1.15 % WP.

2. *Beauveria bassiana* 1.15 % WP.

3. *Beauveria bassiana* 1.15 % WP. (1x108/gm min) Strain BB ICAR-RJP, Accession No–MCC 1022.

4. *Beauveria bassiana* 1.15 % WP (Strain : BB–5372, own R & D Isolate).

5. *Beauveria bassiana* 1.15 % WP (1x108/gm min) Strain ICAR, Research Complex, Umiam, Meghalaya, Accession No –NAIMCC-F-03045.

6. *Beauveria bassiana* 1.15 % WP (1x108 /gm min) Accession No – NAIMCC-F-03045, Strain No. NBAIM, MAU.

7. *Beauveria bassiana* 1.15 % WP (1x108 /spores/ml) Strain BCRL, Accession No–BCRL Bbpx-6892.

8. *Beauveria bassiana* 1.0 % WP, Strain No: NBRI – 9947 (1x108 CFU/gm Min.).

9. *Beauveria bassiana* 1.0 % WP (1x109 CFU/gm min), Strain No. IPL/BB/MI/01.

10. *Beauveria bassiana* 1.0 % WP (1x108 CFU/gm min), Strain No. SVBPU/CSP/Bb-10, Accession No. ITCC- 8 7520.

11. *Beauveria bassiana* 5.0 % WP, (1x108 CFU/gm min) Strain IARI, Accession No. ITCC-7353.

12. *Beauveria bassiana* 5.0 % SC, Strain: NBAII , Bangalore , Accession No. ITCC-7102 (Strain Isolated by Project Directorate of Bio-logical control, Bangalore).

13. *Beauveria bassiana* 5.0 % AS Strain: BB-AAU-RJP Accession No. MCC–1024.

14. *Beauveria bassiana* 1.15 % WP (1x108 /gm min) Accession No – NAIMCC-F-03048.

15. *Beauveria bassiana* 10.00 % SC.

16. *Metarhizium anisopliae* 1.15 % WP (1x108 CFU/gm min) Accession No. MTCC – 5173.

17. *Metarhizium anisopliae* 1.0 % WP (1x108 CFU/gm min) Strain No. IPL/KC/44 (Own R & D Isolate), Accession No. 6895.

18. *Metarhizium anisopliae* 1.15 % WP (1x108 CFU/gm min.) Strain No. AAI, Allahabad, Accession No. NAIMCC-F-03037.

19. *Metarhizium anisopliae* 10 % GR (CFU count 1 X 108 /gm. min.) Strain BCRL– Me, Accession No. ITCC 6911.

20. *Trichoderma harzianum* 1.0 % WP (Strain No. IIHR-TH-2 Accessions No. ITCC 6888).

21. *Trichoderma harzianum* 1.5 % WP (Strain No. IIHR-TV-5 Accessions No. ITCC 6889).

22. *Trichoderma viride* 1.5 % WP (Strain No. IIHR-TV-5 Accessions No. ITCC 6889).

23. *Verticillium chlamydosporium* 1.0 % WP, (2x106 CFU/gm min) Strain–IIHR-VC-3 Accession No – ITCC-6898.

24. *Verticillium lecanii* 1.15 % WP, (1x108 CFU/gm min) Strain–AS MEGH-VL Accession No – MCC-1028.

25. *Verticillium Lecanii* 1.50 % Liquid Formulation, (1x108 CFU/ml. min.) Strain–T Stanes VI-1, Accession No–MTCC-5172.

26. *Verticillium lecanii* 3.0 % AS, (strain: Accession No. MCC-1127, Strain No. MPKV/Biocontrol/ RVN/ VL-01.

27. *Verticillium lecanii* 5.0 % SC, (Strain: Accession No. NFCCI–2638.

28. *Verticillium lecanii* 5.0 % SC, (1x108 CFU/gm Min.) Strain–Own Red Isolate, Strain No. VI-17874, MTCC No.5716.

iii. Virus strains with the available formulation

It is most effective against *Helicoverpa and Spodoptera* larvae in various crops. (CIB & RC, 2021).

1. *Nuclear Polyhedrosis Virus* of *Helicoverpa armigera* 0.43 % AS (1x109 POB/ml).

2. *Nuclear Polyhedrosis Virus* of *Helicoverpa armigera* 2.0 % AS, Strain No. GBS/HNPV -01 (1x109 POB/ml Min.).

3. *Nuclear Polyhedrosis Virus* of *Helicoverpa armigera* 2.0 % AS, Strain No. NBRI-8821 (1x109 POB/ml Min.).

4. *Nuclear Polyhedrosis Virus* of *Helicoverpa armigera* 2.0 % AS, Strain No. IBH-17268 (1x109 POB/ml Min.).

5. *Nuclear Polyhedrosis Virus* of *Helicoverpa armigera* 2.0 % AS, Strain No. BIL/HV-9 POB(1x109 POB/ml Min.).

6. *Nuclear Polyhedrosis Virus* of *Helicoverpa armigera* 2.0 % AS, Strain No. IBL-17268.

7. *Nuclear Polyhedrosis Virus* of *Helicoverpa armigera* 0.43 % AS, Strain No. BIL/HV-9 (1x109 POB/ml Min.).

8. *Nuclear Polyhedrosis Virus* of *Spodoptera litura* 0.5 % AS, (1x109 POB/ml Min.).

9. *NPV* of *Helicoverpa armigera* 0.5 % AS, (1x109 POB/ml Min.).

10. *NPV* of *Helicoverpa armigera* 2.0 % AS, (1x109 POBs count/ ml min) Biological Insecticide.

iv. Protozoa strains

This is most effective against Lepidoptera, beetles, locusts, and other Orthoptera.

1. *Nosema locustae* (3 × 5 μm).

2. *Farinocystis triboli*.

v. Entomopathogenic Nematodes

Following genus of nematodes are effective against coleopteran beetle and weevils, lepidopteran caterpillars, hemipterans insects, etc.

1. *Steinernema carpocapsae*

2. *Steinernema feltiae*

3. *Steinernema kraussei*

4. *Heterorhabditis bacteriophora*

5. *Heterorhabditis downesi*

6. *Phasmarhabditis hermaphrodita*

References

ATSDR (Agency for Toxic Substances and Disease Registry). 2018. Toxicological Profile for 1,2-Dibromoethane. Public Health Service, U.S. Department of Health and Human Services, Atlanta, GA. 1992.

Bloomquist, Jeffrey R. 1993. Toxicology, mode of action, and target site-mediated resistance to insecticides acting on chloride channels. *Comparative Biochemistry and Physiology*, 106 (2):301–314. doi:10.1016/0742-8413 (93)90138-b. PMID 7904908.

Bloomquist,Jeffrey R. 1996. Ion Channels as Targets for Insecticides. *Annual Reviewof Entomology*,41:163–90.doi:10.1146/annurev.en.41.010196.001 .15 PMID 8546445.

Bloomquist, Jeffrey R. 2003. Chloride channels as tools for developing selective insecticides. *Archives of Insect Biochemistry and Physiology*,54 (4): 145-56. doi:10.1002/arch.10112. PMID 14635176.

Bond, E.J. 1989. Fumigation of large structures. *Manual of fumigation for insect control*, https://www.fao.org/3/X5042E/x5042E0k.htm#Fumigation%20of%20 large%20structures.

Britannica, The Editors of Encyclopaedia. "Fumigant" Encyclopedia Britannica,28 Nov. 2019, https://www.britannica.com/technology/fumigant. Accessed 14 October 2021.

CHEBI:142441. 2018. D-D mixture. https://www.ebi.ac.uk/chebi/searchId.do;jsessionid=FB7C52106EE9494EA75429A5D5618D5D?chebiId=CHEBI:142441.

CIB & RC. 2021. Major Uses of Biopesticides (30/06/2021). pp, 01-14.

Cully, Doris, F., Vassilatis, Demetrios, K., Liu, Ken. K., Paress, Philip, S., Van, Der, Ploeg., Lex, H. T., Schaeffer, James, M. and Arena, Joseph, P. 1994. Cloning of an avermectin-sensitive glutamate-gated chloride channel from *Caenorhabditis elegans*. *Nature*, 371 (6499): 70711. Bibcode:1994 Nature. 371..707C. doi:10.1038/371707a0. PMID 7935817. S2CID 43370 14.

David BV, Ramamurthy VV. Elements of Economic Entomology. Ed 8th, Brillion Publishing, New York- New Delhi, 2017, 305-341.

Detlef, Wollweber and Klaus, Tietjen.1999. Chloronicotinyl Insecticides: A Success of the New Chemistry. Nicotinoid Insecticides and the Nicotinic Acetylcholine Receptor, pp 109-125.

FAO. 1996. Data Sheets On Pesticides: Bromadiolone, WHO/PCS/DS/96.88, No. 88.

FAO. 2000. Specifications and Evaluations for Agricultural Pesticides: Thiamethoxam" pp, 1- 34.

Hertlein, Mark., Gary, D. Thompson., Bhadriraju, Subramanyam., Christos, G. Athanassiou. 2011. Spinosad: A new natural product for stored grain protection. Stored Products. 47 (3):131–146. doi:10.1016/j.jspr.2011.01.004. Retrieved 3 May 2012.

Jin, N. 2014. Diflubenzuron. *Encyclopedia of Toxicology (Third Edition)*, pp, 146-148. https://doi.org/10.1016/B978-0-12-386454-3.00133-0.

Mertz, Frederick., Raymond, C. Yao. 1990. Saccharopolyspora spinosa sp. nov. Isolated from soil Collected in a Sugar Mill Rum Still. *International Journal of Systematic Bacteriology*, 40 (1): 34–39. doi:10.1099/00207713-40-1-34.

Omkar, Gavkare., Meena, U. Patil, A.V., Kulkarni and Surabhi, Gupta. 2013. New Group of Insecticides, *Popular Kheti*,-1(3):34-39.

Park, W., Lim, W., Park, S., Whang, K. Y., & Song, G. (2020). Exposure to etoxazole induces mitochondria-mediated apoptosis in porcine trophectoderm and uterine luminal epithelial cells. *Environmental Pollution*, 257,[113480]. https://doi.org/10.1016/j.envpol.2019.113480

Prasad TV. Handbook Of Entomology. Revised ed, New Vishal Publication, New Delhi, 230-236.

Reddy DS. Applied Entomology. New Vishal Publication, New Delhi, 109-130.

Srivastava RP, Saxena RC. Textbook of insect toxicology. Himanshu publication, Udaiapur, 24-70.

Thatheyus, A., J. and Deborah, A., Gnana, Selvam.. 2013. Synthetic Pyrethroids: Toxicity and Biodegradation. *Applied Ecology and Environmental Sciences*, 2013 1 (3), pp 33-36. DOI: 10.12691/aees-1-3-2.

Toranmal, S.S., Buchade, R. S., Tandale, S. D., Wagh, V.H., Chaure, P. P. 2019. Development and Validation of Stability Indicating HPLC Method for Simultaneous Estimation of Milbemycin Oxime and Praziquantel from Bulk and Marketed Formulation. *J. Pharm. Sci. & Res.*, 11(9), 2019, 3108-3115.

Watson, Gerald. 2001. Actions of Insecticidal Spinosyns on gama-Aminobutyric Acid Responses for Small-Diameter Cockroach Neurons. *Pesticide Biochemistry and Physiology*, 71: 20–28. doi:10.1006/pest.2001.2559.

Wolstenholme, Adrian J. 2012. Glutamate-gated Chloride Channels. Journal of Biological Chemistry. *American Society for Biochemistry & Molecular Biology*, 287 (48):40232–40238. doi:10.1074/jbc.r112.406280. ISSN 00219258. PMC 3504739. PMID 23038250.

Chapter - 6

Pesticides and its Management, Purchase, Uses, and Safety

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Introduction

Pesticide is a chemical agent or substance used to destroy insects or other harmful to cultivated plants and animals. The term "pesticides" can be applied to a broad spectrum of chemicals, including rodenticides, insecticides, fungicides, herbicides, biocides, and similar chemicals. Pesticides have been extensively studied since the 1960s, and their chemical and toxicological properties, fate, and transport are well known. Pesticides are pretty unique among chemicals. They are deliberately added to the environment to kill or injure some form of pests' life. Pesticides are substances meant for many purposes, such as preventing, repelling, destroying, or mitigating pest insects, rodents, weeds, and other unwanted organisms. While some pesticides are selectively toxic only to target species, many pesticides are not highly selective and are harmful to non-target species, including humans. All the more, pesticides are often classified based on the target species they act on. Different types of pesticides are known, with other uses, toxicity, and mode of action.

Risks Posed by Pesticides

There is no risk-free pesticide. Pesticides are toxic to pests, mammals, and human beings, and pets to some degree, but the degree of toxicity varies from animal to animal. We can minimize the associated risk of pesticides and their residues that may arise by improving our understanding from purchase to use. If suitable precautions are taken, they do not prove hazardous to humans and non-target animal species in the aquatic and terrestrial ecosystems. Most pesticides and their nondegradable residues will cause adverse effects if accidentally or intentionally ingested or exposed to humans and in contact with the skin for a long time. An additional risk is the inhalation of pesticides while spraying or contaminating drinking water, food, or soil.

Cashew in kasargod, kerala poisonous nuts

Endosulfan, a broad-spectrum insecticide and acaricide, has been used in agriculture worldwide to control insect pests, including whiteflies, aphids, mites, thrips, leafhoppers, lepidopterans, and coleopterans. However, as it is not specific, it can negatively impact populations of beneficial insects. It is, however, considered to be moderately toxic to honey bees, and it is less harmful to bees than organophosphate insecticides. It is being phased out globally, including India, due to its acute toxicity, potential for bioaccumulation, and role as an endocrine disruptor. The 2001 Stockholm Convention is slated to be phased out globally, under which India is also a signatory. The pesticide being classified as an organochlorine compound, and its breakdown products are highly persistent in the environment, with an estimated half-life of nine months to six years. They are known to potentially bio-accumulate in humans and other animals› liver, kidneys, and fatty tissue.

It was a highly controversial agrichemical extensively sprayed in the cashew nut plantation in coastal areas of Kerala state. Plantation Corporation of Kerala (PCK) spread endosulfan over 2,209 ha in Kasargod, Kerala. PCK started using this pesticide in 1979 resulted in unusual health disorders from Vaninagar, Adur, Mulleria, Padre, etc., areas in Kerala since the people were unaware of the lethal poison of these pesticides. In their study, the Centre for Science and Environment (CSE) confirmed the presence of high quantities of endosulfan in the samples of water, soil, fruits, vegetables, mother›s milk, and blood. Besides, it is also known to cause various side effects such as central nervous system disorders, cerebral palsy, physical and mental retardation, epilepsy, and congenital anomalies such as stag horns, liver cancer, blood cancer, infertility, miscarriages, hormonal imbalances, skin diseases, and asthma. After several reports by various agencies and mass agitation, endosulfan was banned in Kerala with effect from August 2001. The rehabilitation of the living victims is tough and challenging even though the state government has paid compensations. Reports disclose that approximately 224 people were critically affected, and 226 have a 60 % disability. People suffered this tragedy in over 20 villages in the Kerala state (Sushmitha Baskar and R.Baskar, 2007).

Precautions

Special precautions and guidelines must be taken during the transport, handling, and storage of Pesticides. People who work with pesticides should undergo proper training in their safe use. Spray and used equipment should be regularly cleaned and maintained to prevent leaks. The following precautions should be strictly followed.

1. Before purchase

a. Consultation/Advisory

- Usually, the majority of farmers taking technical advice from the pesticide dealers/distributors only. Since most such dealers are not agriculture graduates who remain vulnerable to wrong and technically not sound, farmers' queries are not clarified appropriately. In the absence of scientific guidance of pests, their group, their life cycle, and improper stewardship, farmers may be misled and advised inappropriately towards the management practices, leading to indiscriminate and unwise use of pesticides.
- Farmers should visit the nearby Krishi Vigyan Kendra (KVK)/SAUs/State Department of Agriculture and consult the scientists/extension workers for appropriate information and advice. Also, try to involve in farmers' field schools, field visits, group discussion, demonstrations, and training organized by Krishi Vigyan Kendra, Agriculture Universities, and State Department of Agriculture to know the crop culture and management technologies properly.

Fig 6.1. Farmers taking advisory and involved in farms visit and training programme

b. Follow farm news on magazines, bulletins, newspapers, social media, etc.

Before selecting pesticides, farmers need to get information about pesticides and their safe use from magazines, bulletins, farmers' dairy, internet, TV, radio, newspapers, etc.

Fig 6.2. Farmers can get information from printed media

c. Selection of pesticides

Pesticides are included as part of the IPM strategy, but they must be used with care and with attention to safety. When using a pesticide, there are specific considerations to keep in mind, especially regarding potential harm to non-target organisms.

Fig 6.3. The selection of pesticides should be based on safety

i. Safety from pesticides

Questions to ask include what is the pesticide's toxicity level, which is measured using LD_{50} value? If higher the LD_{50} value number means less is toxic of pesticide. What is the mobility of pesticide, and in what fashion can it be distributed in the ecosystem (through the air, soil, water, etc.) ?; What is the residual life of the pesticide? and what are the environmental hazards listed on the label attached?

ii. Specificity of pesticides

This is especially important to look for before using toxic pesticides since certain pesticides only affect the target animals or plants. Try to avoid getting broad-spectrum pesticides that can kill or harm many beneficial species along with the pest. If such a pesticide is the only option, try doing spot treatments to reduce the likelihood of affecting non-target organisms.

iii. Effectiveness of pesticides

It isn't easy to measure the effectiveness of pesticides because it can vary depending on where the chemicals are being applied. In a lab, for instance, a chemical may kill a large percentage of the target pest because it is a controlled environment, but in a field situation, the number may be much smaller due to other factors such as killing off natural enemies, temperature changes, rainfall, relative humidity, wind velocity, etc. Evaluating the uses of a considered pesticide in similar situations like your school's may help estimate the kind of effect it will have.

iv. Endurance of pesticides

An animal or plant's endurance to the effects of a pesticide may vary. Watch for success in pest control: if it initially seems to work well but then later populations grow despite continued use, there may be some built-up resistance.

v. Interaction of pesticides with target organisms

Choosing a pesticide should be determined based on circumstances. If it is an emergency, a shorter-lived, fast-acting, and more acutely toxic pesticide (such as organophosphate for cockroaches) may be necessary. But longer-lasting, slow-acting, and less toxic pesticides with the most miniature residual life may be better for chronic pest problems.

vi. Cost-effectiveness of pesticides

This is always a consideration when deciding what pesticide to be used. Determination of cost often is done by measuring rupees per volume. Some new pesticides that are effective in lower doses may be more expensive than older or conventional pesticides that need more significant amounts to control pests effectively. A small container of more concentrated pesticide may seem more costly but may be as effective as three times that much in another kind of pesticide.

vii. Once a pesticide is selected, notify about it to others too

Give notification to farmers, personnel, students, and parents about what pesticide will be (or has been) used and where it will be (or has been) applied, so they are aware of any possible exposure in the field and storage conditions.

2. While purchasing

Pesticides should be carefully packed and labeled according to WHO specifications. Always keep pesticides in their original containers with the proper labels in English and the local language. The label should indicate important contents, safety instructions (warnings), and possible actions to be taken in the event of swallowing or contamination.

Fig 6.4. Reading pesticides labels on containers to confirm the authenticity of a product

Table 1. Precautions while purchasing pesticides

Do's	Don't
» Purchase pesticides only from registered pesticide dealers with valid licenses. » Purchase only just the required amount of pesticides for a single operation in a specified. » Check for approved labels on the containers/packets of pesticides » Check for batch No, Registration No, Date, and year of Manufacture/ Expiry on the labels. » Purchase only well-packed pesticides in containers. » Always purchase with proper bill or invoice and all details like batch number, manufacturing date & expiry date should be mentioned in it	» Do not purchase pesticides from roadside dealers or un-licensed people. » Do not purchase pesticides in bulk for a whole season. » Do not purchase pesticides without an approved label with instructions on the containers. » Never purchase expired pesticides. » Do not purchase pesticides with leak/loose/unsealed containers. » Never purchase pesticides without a bill.

(Source:-www.ppqs.gov.in)

3. While handling

A person handling pesticides should avoid any contact of the pesticides with their bare skin and inhalation or ingestion of vapors or mists. They should wear rubber gloves for protection, and the face should be covered with a suitable mask to avoid unnecessary inhalation.

Table 2. Precautions while handling pesticides

Do's	**Don't**
» Keep pesticides separate during transportation » Bulk pesticides should be carried tactfully to the site of application	» Never carry/transport pesticides along with food/ items /fodder/ other edible articles » Never carry bulk pesticides on the bare head, shoulder, or the back

(Source:-www.ppqs.gov.in)

4. **Selection of equipment**

Selection and use of spraying equipment should be made based on the frequency of pesticide application, availability of diluents (water, oil, kerosene, etc.). Availability of labour (human or animal power), an area requiring treatment durability, cost of equipment, availability of after-sales service, operating cost, and speed needed to cover an area (this will depend on the type of crop, stage of crop growth, and volume of spray solution to be applied respectively).

Table 3. Precautions during a selection of equipment

Do's	Don't
» Select the right kind of equipment. » Select right sized nozzle.	» Do not use leaky or defective equipment. » Do not use defective/non-suggested nozzles. Do not blow/clean clogged nozzles with the mouth directly. Instead, used a toothbrush tied with a sprayer. Never use the same sprayer for more than one pesticide. E.g., weedicides and insecticides.

(Source: - www.ppqs.gov.in)

5. **While preparing spray solution**

Special precautions must be taken during the mixing and packing of insecticides in bags. In addition to the protective clothing, it is recommended that gloves, an apron, and eye protection such as a face shield or goggles be worn. Face shields are more fantastic to wear and provide protection for the whole face. The mouth and nose should be covered, as recommended for indoor spraying. Special precautions should be taken not to touch any part of the body with gloves while handling pesticides.

Table 4. Precautions while preparing spray solution

Do's	Don't
» Always use clean water.	» Do not use muddy, dirty, or stagnant water.
» Use protective coverings viz., face masks, hand gloves, apron, cap, full trouser, etc., to protect the whole body.	» Never prepare spray solution without protective clothing.
» Always protect your eyes, nose, hands, ears, etc. From the chemical spill of spray solution.	» Do not allow the pesticides/spray solution to fall on any body parts.
» Read instructions on pesticides container labels carefully before use.	» Never avoid reading instructions on containers label for use.
» Prepare fresh solution as per requirement.	» Never use left-out spray solution after 24 hrs of its preparation.
» Granular pesticides should be used as they are.	» Do not mix granules with water to form a solution.
» While filling the spray tank, avoid spilling pesticides solutions	» Do not smell the spray tank to avoid inhalation of chemicals.
» Always use correct & recommended dosage of pesticides.	» Do not use a higher dose than recommended, which may affect plant health and the environment.
» Care should be taken to avoid activities that may affect your health.	» Do not drink, eat, chew or smoke during the whole operation of pesticides.

(Source:-www.ppqs.gov.in)

Fig 6.5. Protection kit while handling and spraying pesticide

6. While applying spray solution

Spray workers should wear overalls or shirts with long sleeves and trousers, a turban or other headgear, a broad-brimmed hat, either sturdy shoes or boots. Sandals are unsuitable, therefore not recommended. The mouth and nose should be covered with simple protective clothing such as a surgical-type disposable or washable mask, disposable paper mask, or any clean piece of cotton cloth. The cotton should be changed or replaced if it becomes wet. The clothing should be of cotton for ease of handling, like washing and drying. It should cover the whole body without any openings. In hot and humid climates, wearing additional protective clothing may be uncomfortable; therefore, pesticides should be applied during the cooler hours of the day.

The discharge from the sprayer should be such that it should be directed away from the body. Leaked equipment should be repaired or replaced. In case of any accidental contamination, the skin should be washed immediately. During indoor spraying operations, persons and domestic animals must not remain inside. Rooms must not be sprayed if someone, e.g., a sick person. Before spraying operation, cooking utensils, food, and drinking-water containers should be kept outdoors to avoid contamination. They can be placed in the center of a room and covered with a plastic sheet otherwise. Paintings and pictures, hammocks, etc., must be protected. In any case, if furniture has to be sprayed on the lower side and the side next to a wall, care should be taken to ensure that other surfaces are not left unsprayed. After every spray, floors should be swept clean or washed. Inhabitants should avoid contact with the walls at any cost. Clothes and equipment used should be washed daily. Long duration exposure to chemicals such as Organophosphorus and carbamate compounds should be avoided. They should not be applied for more than 5–6 hrs a day, and the hands should be washed after every pump charge. If Fenitrothion or old stocks of malathion are used, blood cholinesterase activity of spray personnel should be checked weekly.

Table 5. Precautions while applying spray solution

Do's	**Don't**
» Apply only correct and recommended dose and dilution. Spray operation should be conducted only on a cool and calm day. » Spray operation should be conducted generally on a sunny day. » Use recommended/separate sprayer for each spray. » Spray operation should be conducted in the direction of the wind. » The sprayer and buckets should be washed with clean water using detergent/soap after each spray operation. » Restrict entry of workers and animals in the field immediately after spray.	» Never apply over-dose and higher concentrations than recommended. » Do not spray on a hot sunny day or under windy solid conditions. » Avoid spraying just before rains and immediately after the rain. » Battery operated ULV sprayer should not be used for spraying emulsifiable concentrate (EC) formulations » Do not spray against the wind direction. » Never used Containers and buckets used for mixing pesticides for domestic purposes even after thorough washing. Avoid entry in the treated field immediately after spray without wearing protective clothing.

(Source:-www.ppqs.gov.in)

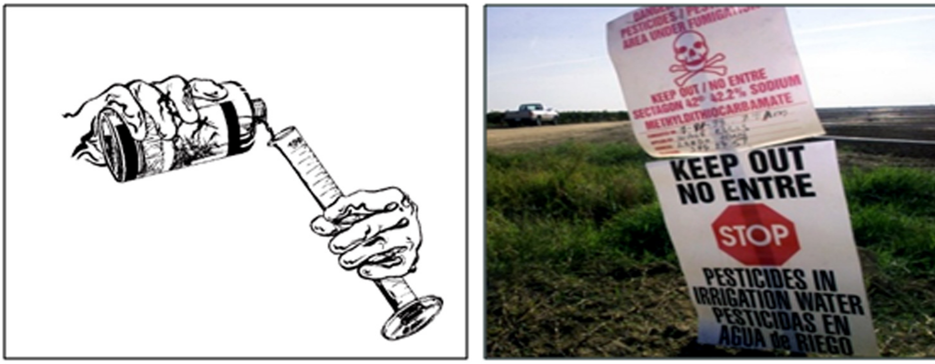

Fig 6.6. Use only recommended dose and restrict entry after application

a. Impregnation of fabrics

In a few instances, extra protection may be required, e.g., from dust, vapour, or spray of hazardous products. Such additional protective items should be indicated on the product label, including aprons, boots, face masks, overalls, and hats.

b. Maintenance

Clothing should be kept in good condition and regularly inspected for tears or worn areas where skin contamination might occur. Protective clothing and equipment should be washed daily with detergent, separately from other clothing. Special attention should be given to clothes and replaced when there is any wear and tear. Gloves should be rinsed immediately after use with clean water before they are taken off. At the end of each working day, they should be thoroughly washed inside and outside.

c. General precautions

While using insecticide, avoid eating, drinking, or smoking. Always keep the food in a tight container. This will prevent accidental ingestion of insecticides. Various suitable equipment should be used for measuring the required quantity, mixing, and transferring insecticides. Avoid stirring or scooping of pesticide with bare hands. To release pressure, use a pressure-release valve of the pump or a soft probe to clear blockages in the nozzle. One must wash their hands and faces with soap and water each time the pump is refilled. Eat and drink only after washing the hands and face. Take a thorough shower or bath at the end of the day.

7. After spray operation

Table 6. Precautions after spray operation

Do's	Don't
» Leftover spray solutions should be discarded at safer places such as a desolate plots of land.	» Leftover spray solutions should not be drained or disposed of in or near ponds or water lines etc.
» The used/empty containers should be crushed and buried deep in the soil away from water sources.	» Empty containers of pesticides should not be reused for storing other items.
» Wash hands and face thoroughly with clean water and soap before eating/smoking.	» Never eat/smoke without washing hands or before washing clothes and taking a bath.
» On observing poisoning symptoms, give first aid immediately and take the patient to the doctor. Also, carry the empty container to the doctor	» Do not take a risk by not showing the poisoning symptoms to the doctor as it may endanger the patient's life

(Source:-www.ppqs.gov.in)

Wait for PHI (Pre-Harvest Interval) before harvest/plucking

- » Never harvest or pluck fruits and vegetables on the same day of spraying.
- » Observe the approved minimum waiting period from the day of spray to avoid health risks from pesticide residues.
- » Maintain a record of the day(s) of spraying to determine the waiting period.

8. Disposal

Disposal of leftover insecticide suspension should be carefully treaded. For instance, a safe way to discard leftover suspensions is to dig a hole in the ground specifically to pour them in. This could be done in pit latrines as well. It should not be disposed of where it may permeate water used for drinking or washing, fish ponds, or rivers because certain insecticides like pyrethroids are highly toxic to fish. Thus, these holes in the suggestion should be dug at least 100 meters away from streams, wells, and houses. In hilly areas, the hole should be on the lower side of such areas. Any trace of pesticides - run-off water from washing hands, spray washings, containers, bottles, boxes – can be thrown and buried in the hole. The hole must then be closed as soon as possible. Cardboard, paper, and clean plastic containers that can be burned permitted, albeit far away from houses and drinking water sources.

Furthermore, dry grounds are ideal places for disposal as they can be quickly absorbed and degraded without posing environmental hazards. Surplus solutions have various household usages. For example, they can kill insect pests such as ants and cockroaches by pouring or sponging them onto infested areas. Insect breeding can also be temporarily reduced by pouring the solution in and around latrines or similar breeding places. Solutions of pyrethroids, when prepared carefully, can be used for the treatment of many items - mosquito nets, fabrics, sleeping mats, or string mattresses – to ward off mosquitoes as well as bed bugs.

Fig 6.7. Safe disposal (a) and improper disposal (b) of empty pesticide containers

Fig 6.8. Wash hands and face thoroughly with clean water and soap before eating/smoking

9. During storage

Pesticides must be stored in places that can be locked and are not easily accessible to unauthorized people or children. They should never be kept in a place where they might be mistaken for food or drink. Keep them dry but away from fires and out of direct sunlight. Do not carry the pesticides in a vehicle that is also used to transport food.

Table 7. Precautions during storage

Do’s	Don’t
» Store the pesticide away from houses and their surroundings.	» Never store pesticides in houses and surroundings.
» Store pesticides in their original containers	» Never replace the original containers of pesticides.
» Store pesticides and weedicides separately.	» Avoid storing insecticides with weedicides.
» Mark the area with warning signs where pesticides have been stored.	» Do not leave the pesticides storage area to unmark.
» Keep the pesticides away from the reach of children and livestock.	» Do not allow children to enter the storage premises.
» Storage premises should be well protected from direct sunlight and rain.	» Never expose pesticides to sunlight or rainwater.

(Source:-www.ppqs.gov.in)

Fig 6.9. Keep the pesticides away from the reach of children and livestock.

The incidence which occurred in Bhopal, also referred to as the Bhopal gas tragedy, was a gas leak incident on the night of December 2-3, 1984 at the Union Carbide India Limited (UCIL) pesticide plant in Bhopal, Madhya Pradesh, India. Till date, it is considered among the world's worst industrial disasters. Over 5, 00,000 people were exposed to the deadly methyl isocyanate (MIC) gas.

Date : 2 December 1984 – 3 December 1984

Deaths : At least 3,787; over 16,000 claimed

Location : Bhopal, Madhya Pradesh, India

Pesticide containers should not be reused due to the risks they impose and hence are not recommended. Nevertheless, some may hesitate to discard empty pesticide containers as they may hold reusable value. Whether containers are suitable for reuse depends on the material they are made of and the chemicals contained in them. The possibilities for reuse and cleaning procedures should be provided in the instruction label. Containers that have held pesticide formulations classified as highly hazardous or highly hazardous must not be reused. Under certain conditions, containers of pesticide formulations classified as slightly hazardous or unlikely to present acute hazard in general use can be reused for purposes other than the storage of food, drink, or animal feed. Containers made of materials such as polyethylene should not be reused as they are known to absorb pesticides in which the active ingredient is classified as moderately, highly, or highly hazardous, regardless of the formulation. Pesticide containers should be rinsed immediately after exhaustion, filled with water, and allowed to stand for 24 hours. They then should be emptied, and the process should be repeated twice.

In July 19, 2013, a cook serves the free mid-day meal, distributed by a government-run primary school, to children at Brahimpur village in Chapra district of the eastern Indian state of Bihar which claimed the lives of 23 children, was most probably caused by storing cooking oil in a used Monocrotophos pesticide container. Monocrotophos is an insecticide which is toxic to birds and humans. The World Health Organization describes it as highly hazardous and advises that its handling should only be undertaken by well trained and competently supervised users.All material contaminated with the chemical should be destroyed in a high-temperature chemical incinerator, according to the Food and Agriculture Organisation of the United Nations. It has been banned in several countries, including India & USA

Safety Measures

Recognize poisoning symptoms of pesticides

Most of the poisonings due to pesticides are usually acute and result from extensive skin contact or ingestion. However, the signs and symptoms vary with the type of pesticide used and can sometimes be confused with those of other illnesses. Some of the poisoning signs and symptoms are as blows.

- **General :** Intense weakness and fatigue.
- **Skin :** Irritation, burning sensation, excessive sweating, staining.
- **Eyes:** Itching, burning sensation, watering, difficult or blurred vision, narrowed or widened pupils.
- **Digestive system :** Burning sensation in mouth and throat, excessive salivation, nausea, vomiting, abdominal pain, diarrhoea.
- **Nervous system :** Headaches, dizziness, confusion, restlessness, muscle twitching, staggering gait, slurred speech, fits, unconsciousness.
- **Respiratory system :** Cough, chest pain and tightness, difficulty with breathing, wheezing.

If the above poisoning signs and symptoms are found on the patient, additional information must be obtained to go for further medical treatment and assistance.

- Has the patient been working with a pesticide?
- Any presence/record of contamination?
- The specific information of the product used?
- The amount/quantity ingested?
- How long ago with a specific time?

The labels on the containers should be read retained to obtain evidence from pesticide containers or spray equipment. If any case of suspected pesticide poisoning, first aid must be given immediately, and medical help and advice must be sought at the earliest. The patient should be taken to the nearest medical facility as soon as possible.

First-Aid Treatment

1. In respiratory difficulties

Artificial respiration should be given. Mouth-to-mouth resuscitation may be given if there is no swallowing of insecticide. To clear the airway, pull the patient's chin up and tilt the head back with one hand and place the other hand on the patient's forehead, with the thumb and index finger toward the nose. Pinch the patient's nostrils together with the thumb and index finger to prevent air from escaping. Take a deep breath to form a tight seal with your mouth over and around the patient's mouth. Give four quick blows, with full breaths in first without allowing the lungs to deflate fully. At the same time, observe the patient's chest while inflating the lungs. The chest of the patient should rise and fall if adequate respiration occurs. Once this happens, allow the patient to breathe out on his own. By forming a tight seal around the patient's mouth, take another deep breath and blow into the mouth again. This procedure has to be repeated 10–12 times a minute (once every five seconds). As long as there is a pulse, artificial respiration should be continued. However, if insecticide has been swallowed, another form of artificial ventilation should be used.

2. In skin or eyes, contamination

Rinses the eyes with large quantities of clean water for at least five min. remove contaminated clothing from the patient and remove the patient from the contaminated area. Wash the body entirely for at least 10 min, using soap if possible. If no water is available, wipe the skin gently with cloths or paper to soak up the pesticide. Harsh rubbing or scrubbing of the eye should be avoided.

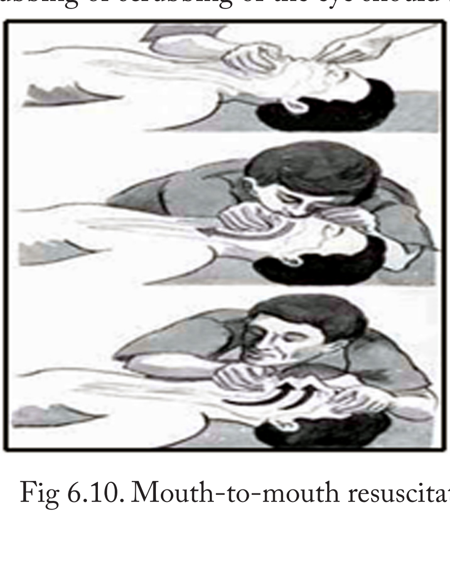

Fig 6.10. Mouth-to-mouth resuscitation and rinsing of eyes under tap water

3. In vomiting

Avoid inducing vomit unless the patient has swallowed pesticide that is known to be highly toxic, and medical help is not expected soon. Never induce vomiting if the patient has swallowed oil spray or products diluted in diesel or kerosene because of the possibility of inhalation of the vomited material, which would be more dangerous than intestinal poisoning. The product label should indicate whether the pesticide is highly toxic (skull-and-crossbones signs). Induce vomiting only on a conscious patient. Sit or stand the person up and tickle the back of the throat with a finger if required. Whether vomiting occurs or not, give the patient a drink comprising three tablespoonfuls of activated charcoal in half a glass of water. Continue the procedure until medical help arrives.

4. For symptomatic patients

Make the patient lie down and rest because poisoning with organophosphorus and carbamate compounds is made worse by movement. Place the patient on their side with the head lower than the body. If the patient is unconscious, pull the chin forward and head back to ensure a clear airway. Cover the patient with a blanket if he or she feels cold, and cool the patient by sponging with cold water if excessive sweating occurs. If the patient vomits spontaneously, ensure that he or she does not inhale the vomit. In the event of convulsions, put padded material between the teeth to avoid injury. Do not allow patients to smoke or drink alcohol. Do not give milk. Water can be given.

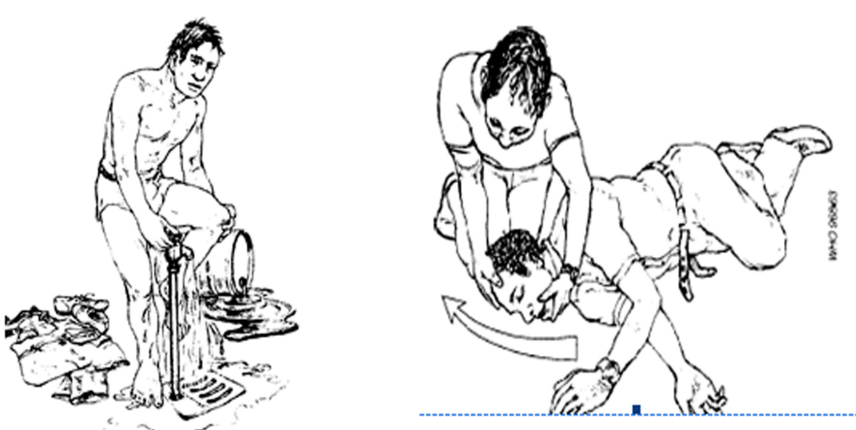

Fig 6.11. Remove contaminated clothing immediately and wash the skin & Place an unconscious patient on her or his side and tilt the head back

Further treatment in acute poisoning

Patients requiring further medical treatment should be referred to the nearest medical facility. WHO is preparing detailed guidelines for the management of poisoning.

References

Sushmitha, Baskar and R. Baskar. 2007. Environmental Studies for Undergraduate Courses. Unicorn Books. New Delhi, India.

Guidelines for emergency measures in cases of pesticide poisoning. Brussels, International Group of National Associations of Manufacturers of Agrochemical Products, 1984.

Guidelines for personal protection when using pesticides in hot climates. Brussels, International. Group of National Associations of Manufacturers of Agrochemical Products, 1989.

Guidelines for the avoidance, limitation, and disposal of pesticide waste on the farm. Brussels, International Group of National Associations of Manufacturers of Agrochemical Products, 1987.

Guidelines for the safe and effective use of pesticides. Brussels, International Group of National Associations of Manufacturers of Agrochemical Products, 1989.

Henry, J. and Wiseman, H. Management of poisoning: a handbook for health care workers. Geneva, World Health Organization, in press.

International Programme on Chemical Safety/World Federation of Associations of Clinical Toxicology Centres and Poison Control Centres. Yellow Tox. World directory of poisons centers. Geneva, World Health Organization, 1993 (unpublished document; available on request from the International Programme on Chemical Safety, World Health Organization, 1211 Geneva 27, Switzerland).

P. K. Chakrabarty., Rajib, Karmakar., Selvakumaran, Sellappan., M. S. Saharan., Kalyan, K. Mondal., M. S. Gurjar and Robin, Gogoi. 2021. Technical Bulletin on Stewardship for Safe Use and Handling of Pesticides. Indian Phytopathological Society, IARI, New Delhi, India, 82 pp.

Specifications for pesticides used in public health: insecticides, molluscicides, repellents, methods, 6th ed. Geneva, World Health Organization, 1985.

Mossler, Mark., Michael, J., Aerts, O. and Norman, Nesheim. 2006. "Florida Crop/Pest Management Profiles: Tomatoes. CIR 1238" (PDF).University of Florida, IFAS Extension. Archived from the original (PDF) on 2009-03-27. Retrieved 2009-01-27.

Extension Toxicology Network. 1996. Pesticide Information Profile: Endosulfan. Oregon State University.

USEPA, 2006. Reregistration Eligibility Decision for Endosulfan Archived 2006-10-06 at the Wayback Machine, November 2002.

Institute of Agriculture and Natural Resources. 2021. Pesticide Safety Education Program. University Of Nebraska–Lincoln.

The entire picture from Google scholars.

Selected further reading

Guidelines for the safe handling of pesticides during their formulation, packing, storage, and transport. 1982. Brussels, International Group of National Associations of Manufacturers of Agrochemical Products, 1982.

International Programme on Chemical Safety. 1994. The WHO recommended the classification of pesticides by hazard and guidelines to classification 1994–1995. Geneva, World Health Organization, 1994 (unpublished document WHO/PCS/94.2; available on request from Programme for the Promotion of Chemical Safety, World Health Organization, 1211Geneva 27, Switzerland).

Safe use of pesticides. 1990. Fourteenth report of the WHO Expert Committee on Vector Biology and Control. Geneva, World Health Organization, 1990 (WHO Technical Report Series, No.813).

Chapter - 7

Bioassay of Pesticide and its Importance in Toxicity Testing

R. Lalrinfeli and C. G. Sawant

Introduction

Bioassay comprises two words - 'bios' meaning life and 'assay' meaning determination. It is the determination of the response of a chemical on a living organism. Bioassay or biological assay implies the measurement of the effect of insecticides on living organisms. Finney (1952) described bioassay as the measurement of the potency of any stimulus, physical, chemical, biological, physiological or psychological, etc., using the reaction it produces in a living organism'.

In the late 19th century, a bioassay was first used when Paul Ehrlich, the German physician, laid down the foundation of bioassays. Paul introduced the concept of standardization by the reactions of living matter. The first bioassay to receive recognition was the bioassay on diphtheria antitoxin by him.

Bioassays carried out in the laboratory have become increasingly important because of their predictive value, generating comparative toxicity data in relatively short times at relatively low expense on many chemicals. Investigations in the laboratory provide a better result and understanding of insect-insecticide or insect-plant-insecticide interactions. This technique is simple, easy, versatile, and sensitive for determining the toxicity of a wide range of chemicals, which significantly facilitates the determination of the LD_{50}, $LC_{50,}$ or any other lethal concentration/dose. This chapter explains the different laboratory bioassay techniques and their importance for evaluating different insecticides against insect pests.

Need of Bioassay in Pesticide Testing

Crop damages and losses due to pests and diseases are a significant threat to thousands of rural families' incomes and food security. Insect pests are attacking crops right from germination to harvesting. Different synthetic insecticides such as chemicals are still considered the mainstay of agricultural pest control. Even though the development of resistance against insecticides is a common phenomenon, recent advances in research and technology have renewed interest in this subject, and resistance risk assessments have been developed for many species using different assay methods. Evaluating the toxicity of insecticides with the diverse mode of action to the same species under the same test conditions is the essence of bioassay. Due to the increased use of highly toxic insecticides to control destructive insect pests, it is essential to analyze the technical and formulated materials and minute quantities of their residues in plant and animal tissues. The indicator species should be sensitive enough to detect even small insecticides and respond with increasing concentrations in an adequate bioassay. The toxic interactions are dose-dependent of an insecticide with a biological system. The toxicity of an insecticide towards an organism is usually expressed in terms of LD_{50} (lethal dose). This value represents the dose per unit weight lethal to 50 % of the population of the organism. The LD_{50} value is commonly expressed as milligram per kilogram (mg/kg). The LC_{50} (lethal concentration) is often used to represent the concentration of the insecticide in the external media that will kill half of the test population as the exact initial dose given to the insect cannot be determined. It is imperative to note that bioassays are highly sensitive, simple in operation, easily adapted to the assay of newer insecticides, and capable of detecting toxic metabolites. The primary goal of these bioassays is to select newer insecticides to determine the most appropriate doses that affect insects and test pest resistance and the pesticide selectivity to natural enemies. Significant factors of bioassays are the stage of the insects, choice of insecticide bioassay response, application methods, bioassay environment, diet, sample size, sampling, the health of the organism and operator skill, etc. It is equally essential that bioassay data be correlated with the expected field efficacy of the pesticide apart from choosing the correct bioassay technique.

Testing Procedures

Insects are divided into batches and are exposed to particular dosages of an insecticide. The insects to be tested should be free from variations of age, sex, stage, condition of nutrition, etc. Batches as small as 10-20 insects may be tested in precise experimental conditions. Moreover, it is desirable to replicate the batches 3 to 5 times. The collections of insects should be formed in such a way as to ensure that each group is a random sample of the population. The toxicity of insecticide is usually determined using a dose-response relationship. The dosages for testing should be spaced as evenly as possible over the mortality range rather than the dosage itself since the toxic effect is generally related to the logarithm of the dosage. The insects available for testing are divided randomly into several groups, usually six. One group is used as the control group to be treated with just solvent. The remaining groups are treated with the test compound with doses usually in a specific geometric progression (i.e., 1, 2, 4, 6 or 1, 3, 9, 27, etc.). After the insects are exposed to different concentrations of an insecticide, they may or may not be kept in another container with food depending upon the method employed. The mortality count is taken after time already calibrated at different time intervals and when it becomes constant at a particular period. The period of exposure should be fixed. A few insects often die during experiments from natural causes which are not concerned with the insecticide used. The magnitude of this mortality should also be estimated by exposing the batch of insects in control (not treated with insecticide) precisely in the same manner as is done in exposure to insecticide. When there is natural mortality among the controlled subjects, the mortalities have to be corrected by Abbott's formula as follows

$$\text{Corrected mortality (\%)} = \frac{\text{Percent survival in the untreated control} - \text{Percent survival in the treated insects}}{\text{Percent survival in the treated insects}} \times 100$$

Since the mortality in control so obtained will affect the precision of the result. The control mortality rate should be less than 20 %; otherwise, the corrected mortality will not be reliable.

Preparation of stock solutions

For the stock solution, technical grade (95-99% purity) insecticides are used for the laboratory tests. Nevertheless, the active ingredient (a.i) of the insecticides varies. Thus, a 100 % stock solution is prepared using the correction factor (CF): CF= 100% divided by % a.i of the insecticides. For technical insecticide with 99.5 % a.i., CF=100/99.5= 1.005. Given the C.F., compute the weight of the technical insecticide needed to prepare the desired volume and concentration using the formula: Concentration of insecticides x volume x C.F. Eg. To prepare 2.5 ml of 10000 µg/ml stock solution, the weight of insecticide needed will be 10000 µg/ml x 2.5 ml x 1.005 = 25,125 µg or 25.125 mg or 0.025 g. Weigh 0.025g of technical grade insecticide in a 6 ml screw-cap vial using the analytical weighing balance and make up the volume up to 2.5 ml with analytical grade acetone. Secure the cap of the vials with parafilm after preparation to minimize evaporation. The prepared insecticide dilutions should be stored in a refrigerator (4 °C) or freezer (preferably -20 °C). Replace and carefully dispose of the tips after preparation of the insecticide.

Bioassay Methods

Several laboratory bioassay techniques are available to evaluate the toxicity of various insecticides against insect pests. They are:

1. Direct exposure method
2. Topical application method
3. Potter tower's method
4. Injection method
5. Dipping method
6. Contact or Residual method
7. Film method
8. Fumigation method
9. Aqueous solution method
10. Photo migration method
11. Leaf dipping method
12. Sandwich method

1. Direct exposure method

The insects are exposed to materials without extractions. The toxicant may be picked up by insects by feeding, contact, or even as vapour. The mortality counts are made after a specific period.

2. Topical application method

A commonly employed method is topical application, where the insecticide is dissolved in a relatively nontoxic and volatile solvent such as acetone. Tiny measured droplets are applied at a chosen location on the body surface on the thorax of individual third-stage larvae with an operated micro applicator. A motor-driven topical applicator is available with a micrometer-driven precision syringe. The advantages of this method are - the high degree of precision and reproducibility attainable, the ability to perform a large number of tests in a relatively short time, the simplicity and cost-effectiveness of required equipment, the small number of insects (10-20) needed per replication, and the small number of toxicants and solvents required.

Fig. 7.1 Topical application of pesticide

3. Potter's tower method

Uniform spraying or dusting on the body of insects can be done by means of Potter's tower. Potter designed a spray tower with a twin-fluid nozzle mounted centrally at the top of an open-ended metal tube where the sprays fall vertically and deposits on a horizontal plane. The topical application on the entire insect body can be made with Potter's tower by keeping the Petri dish containing a known number of insects under the bottom part of the tower and spraying inside through a nozzle fitted in the lower side by maintaining a particular pressure. This methodology simulates field exposure conditions and hence is effective for pest management. The technique has appeared to be one of the most convenient methods of accurately dispensing available amounts of toxins on insects. However, the significant disadvantages of the method are that it has a slow execution time and a high initial cost due to the necessity of purchasing specific equipment. A detailed description of the process is given below.

3.1 Potter spray tower

The Potter spray tower has been named after C. Potter, the developer of this spray apparatus at Rothamsted Experimental Station, Harpenden, Herts, England. The Potter tower is deliberately recognized as the standard of reference for chemical spraying techniques in the laboratory. This type of device is required for studying the biological effects of contact poisons on organisms. Potter's spray tower is developed to prevent the operator's exposure and contamination to the toxins/ pesticides.

3.1.1 Principle

It works on the principle of constant atmospheric pressure. Continuous supply of 151b/ sq. Through the input connection, which is controlled by an on/off switch and exhaust valve. A sensitive needle valve on the left-hand side is used to make the instrument's fine adjustment, which gives a direct reading on the pressure gauge or manometer (which is supplied as an extra). This pressure operates the air jack and nozzle head simultaneously.

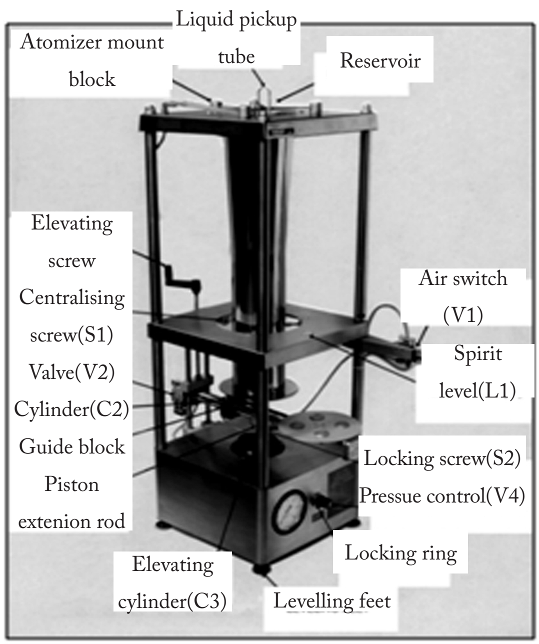

Fig. 7.2 Potter's tower method

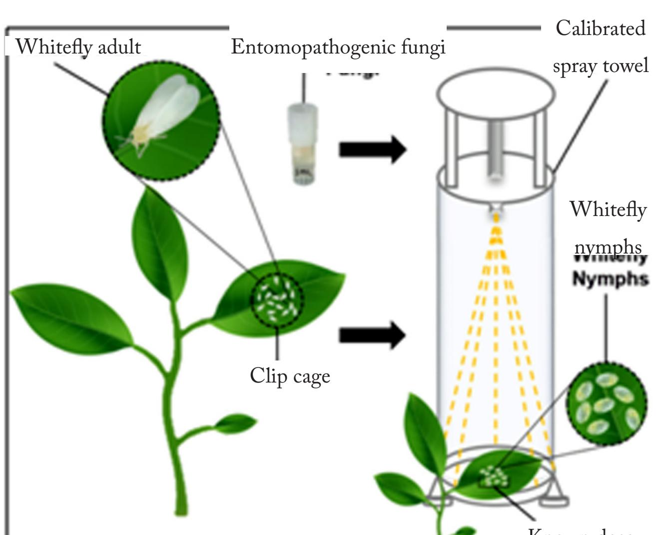

Fig. 7.3 Potter's spray tower method

3.1.2 Instrumentation

The tower is manufactured from an attractively finished high grade of stainless steel. The height of the potter spray tower is 120cm with a standard sample reservoir capacity of 20 cc. Its operating pressure is 151b/sq.in. The tower contains quickly detachable atomizers and a pneumatically operated spray table, with all controls mounted conveniently at the front. This air-operated spraying device applies an even deposit of spray over a circular area of 9 cm diameter. The testing deposit of insecticide is to apply a spray solution or suspension to a Petri dish using a precision sprayer. This device delivers a known spray volume in a frame mist that settles on the surface to be treated. In tests with aphids or spider mites, a leaf substrate contained in a Petri dish can be sprayed by the spraying apparatus.

4. Injection method

The insecticide is directly injected into the insect body (thorax in insects) by a hypodermic needle in this technique. A fine stainless steel needle (27 or 30 gauge thickness and 0.41 or 0.30 mm in diameter) is used, and the quantity of toxicant required is measured by a micrometer. A small glass needle of 0.1-0.16 mm in diameter is used for injection in tiny insects. The insecticide is commonly dissolved in propylene glycol or peanut oil before administering into the insect body through intraperitoneal injection. One must take care to avoid bleeding by the insect. This method is specifically employed to know the exact amount of toxicant needed inside the insect's body.

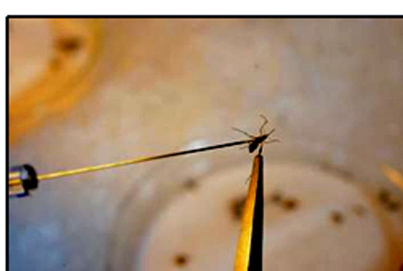

Fig. 7.4 Injection method

5. Dipping method

Maggots of some dipterans are dipped in the insecticidal solution for a few seconds or minutes, depending upon the standardization. This method is employed when the topical application or injection methods are impractical, for example: with stored-product insects, small plant-feeding insects, housefly larvae, insect eggs, red spiders, etc. The insects are picked up with a pair of forceps and dipped into an aqueous chemical solution for short periods. These chemicals may either be a suspension or an emulsion. Insect immersion methods are convenient field-based bioassays useful for extension and field workers. The methods are simple and are somewhat closer to the field application of insecticides. In another dipping method employed, the leaves are dipped in an aqueous solution of insecticides for a definite period in serial dilution of different concentrations. The leaves are carefully drained of excess solutions and air-dried for an hour before being used. After a few minutes, the known numbers of insects feeding on the leaves in question are released, and the mortality counts are done after a definite period. This method can also be employed against sucking insects that are not easily removed from the leaf surface. The leaves containing insects are dipped in insecticidal solution for a definite period, and the population counts before and after an actual interval of dipping are made. This technique permits the product to be evenly distributed on the leaf surface and makes it feasible to check whether or not the field doses are adequate for pest control.

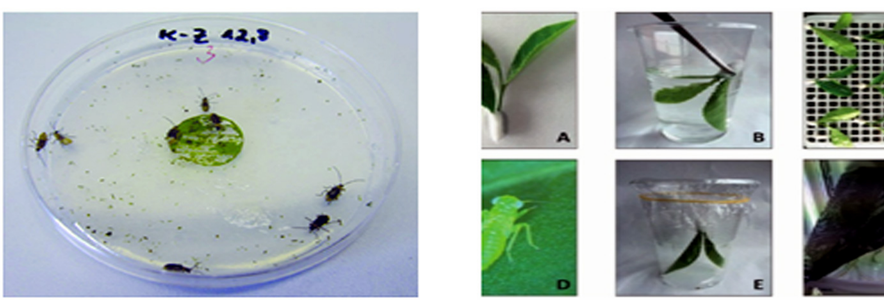

Fig. 7.5 Dipping method

6. Contact or Residual method

In this method, the formulated insecticide is diluted in a volatile solvent (acetone), and the insecticide solution is coated inside a glass vial. The solvent is allowed to evaporate by rotating the container so that the insecticide is spread evenly over the entire surface, leaving a residual film. The dose is varied by the concentration of insecticide solution added to the vials. Insects are released onto the treated surface and thus get exposed to residual film. The insecticide is applied evenly onto the leaf, glass, filter paper, wood panel, or various building materials in an alternate manner and allowed to dry before exposing the insects to the residual deposits. For uniform application, equipment known as Potter's tower is frequently used. The deposits are expressed as milligrams or grams of active ingredient per square meter (mg or g a.i./m^2). However, these techniques do not represent field situations and do not allow us to verify whether doses are being applied efficiently.

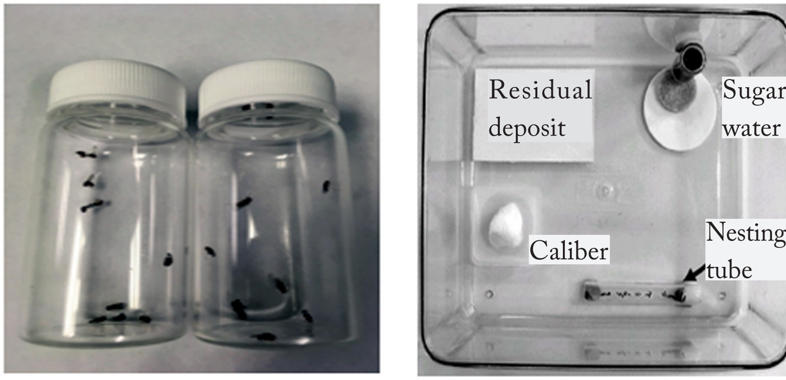

Fig. 7.6 Contact or residual method

7. Film method

The technique involves depositing insecticide solution on glass surfaces such as Petri dish, flask, vial, wide-mouth jar, etc. Petri dishes are most commonly used for evaluating insecticide efficacy. In this approach, Petri dishes (5 cm diameter) are coated with the one-milliliter solution on their inner sides. Then, the solution is spread uniformly in the Petri dish by swirling it gently. It is then allowed to dry up at room temperature. Subsequently, the target insects are released onto the film of the toxicant in the container. After that, the known number of insects are exposed for 18-24 hrs depending upon the recalculation.

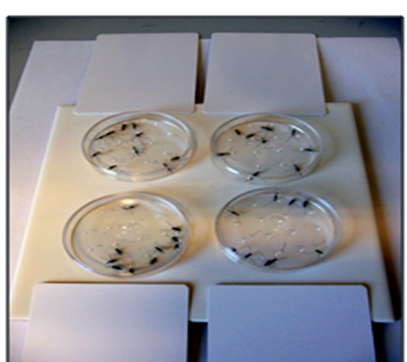

Fig. 7.7 Film method

8. Fumigation method

This is a favorable method for stored-product pests. The fumigation would be performed in a closed chamber at 30 ± 2 °C and 60 ± 5 % relative humidity. The insecticide is introduced into a sealed container along with the insects. Each fumigation test is replicated thrice or more along with control. After exposure, the insects would be provided with a small culture medium for a week and moved to a recovery room. Adult mortality is recorded at different time intervals from the end of the exposure period.

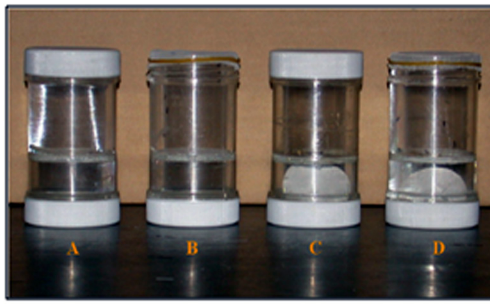

Fig. 7.8 Fumigation method

9. Aqueous solution method

The basic principle of this method is to disseminate the insecticide residue in a small amount of water-miscible solvent (acetone or alcohol) into the water as a solution or suspension. Then a small number of sensitive aquatic organisms such as mosquito larvae, microcrustaceans, or fish are exposed to the solution. The amount of residue in a treated sample is obtained by comparing its toxicity to the standard. The amount of solvent in water should be as little as possible, and its toxicity, if any, can be detected by control tests. This method has the advantage of having the whole organism constantly in contact with the medium. Although some have claimed uniform administration of the toxicant, settling of the suspended material may occur. High sensitivity is thought to result from circulation and absorption of the toxicant through the gills or equivalent organs.

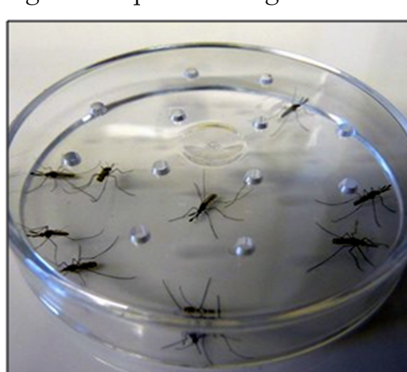

Fig. 7.9 Aqueous solution method

10. Photo migration method

Photo migration method is another aqueous solution method devised by Burchfield using negative phototaxic response to larvae of *Aedes aegypti* (L.). The insecticidal solution is carefully evaporated under a gentle stream of air until dry. The residue is then re-dissolved in a small amount of acetone, after which 50 ml water is added. One to two hundred larvae are then confined behind a porous barrier in a glass trough containing the solution as mentioned above. After varying periods, the light is turned on, and the barrier is removed. Viable larvae rapidly migrate away from the light. After one minute of exposure, a second barrier is kept in the trough, and the larvae left behind are considered dead. From a series of dilutions, LC_{50} and T_{50} (The time required to inactivate 50 % of the test population) are worked out.

The percent mortality corresponding to each dose calculated from the number of insects released and the mortality observed after exposure period. The mortality in control, if any, will affect the precision of the result. To over this error, a correction is usually applied by using Abbott's formula.

The susceptibility of any population to poison is assessed by constructing a dosage-mortality curve in which the dosage is plotted against the mortality percentage at a given period. This type of plot produces a sigmoid curve whose asymptotic approaches (infinite ends) at the regions of zero, and 100% mortality are difficult to define without extensive testing. The sigmoid curve is converted to a straight line in probit transformation by plotting the logarithm of the dosage against the probit value of percent mortality. This computation method yields a straight line, which significantly facilitates the determination of the LC_{50}, $LC_{90,}$ or any other lethal concentration/dose.

11. Leaf dipping method

The leaves are dipped in an aqueous solution of insecticides for a definite period, and then they are taken out. After few minutes, the known number of insects are allowed to feed on these leaves, and the mortality counts are done after a definite period.

12. Sandwich method

In this method, a measured amount of insecticide is put in between two leaves, and the test insect is allowed to feed on it. It is generally used for leaf-eating caterpillars.

Importance of Bioassay in Pesticide Testing

1. Bioassay is adopted to ascertain the potency of the chemicals as insecticides.
2. It helps determine the properties of synergism, potentiation, and antagonism of a compound when used in a mixture with an insecticide.
3. Comparative or relative toxicity of insecticides is worked out based on LC_{50} obtained as a result of bioassay. This gives an index for selecting promising insecticides for field trials against insect pests.
4. Bioassay helps to evaluate insecticides with regards to their safety towards pollinators, predators, and pathogens.
5. Bioassay can help the formulators improve the effectiveness of their formulated products through changes in the solvent, spreader, emulsifier, stickers, etc.
6. The quality of marketed insecticides can be checked through the bioassay of samples collected and by comparing them with the standard.
7. The change in values of LC_{50} of an insecticide for an insect with time indicates variation in susceptibility, which helps detect resistance if developed in the insect population. Cross-resistance to other insecticides, use of synergists, and mixed formulations to overcome resistance are also estimated through bioassay.
8. The formation of toxic metabolites, not quantitatively, due to the use of insecticide can be determined by bioassay.
9. Through bioassay, lethal time (LT_{50}) is required to kill 50 % population to test animals. ED_{50} or $EC_{50,}$ i.e., the dose or concentration of a chemical that brings out sterility or other quantitative effects in 50 % population, can also be worked out.
10. Bioassay can also be utilized to estimate micro quantities, i.e., residues of insecticides in different commodities, to create awareness & warn the consumers of the various hazards associated with it.

Limitations of Bioassay in Pesticide Testing

1. Requirement of the most sensitive organism for particular toxicant.
2. Rearing, handling, and maintaining of uniformity of test organism. There may be the complexity of rearing or assay methods for a specific organism.
3. Sometimes there is the susceptibility of a particular organism to plant toxicity or extractives.

4. Standardization of observation time.
5. There may be significant variation in results with the change in test organism.
6. Lack of specificity in general though there are some instances in which it is peculiar.
7. Does not tell about the quantities of the different toxic metabolites in case of residue determination.

Conclusion

Understanding median lethal dose, lethal concentration, and toxicity are significant for the better evaluation of the toxic of the particular pesticides. Bioassay can be a valuable tool for the determination and study of different agricultural pesticides. It can be simple, swift, versatile, and highly sensitive to a wide range of toxicants. Generally, little or no expensive equipment or highly trained help is required. Although used to best advantage when the toxicant is known, bioassay can be used in some instances to identify toxicants.

References

Abbott, W.S. 1925. A method of computing the effectiveness of an insecticide. *Journal of Economic Entomology*, 18:265-267.

Bacci, L., Picanco, M.C., Barros, E.C., Rosado, J.F., Silva, G.A. and Silva, V.F. 2009. Physiological selectivity of insecticides to wasps (Hymenoptera: Vespidae) preying on the diamondback moth. *Socio-biology*, 53:151-167.

Ball, H.J. 1981. Insecticide resistance - a practical assessment. *Bulletin of the Entomological Society of America*, 27:261-262.

Birah, A., Alpana, B.S., Mahapatro, G.K. and Gupta, P. 2008. Toxicity evaluation of emamectin benzoate against tobacco Caterpillar (Spodoptera litura) by three different assay techniques. *Indian Journal of Entomology,* 70(3):200-205.

Burchfield, H.P., Hilchey, J.D. and Storrs, E. E. 1952. An objective method for insecticide bio- assay based on photo migration of mosquito larvae. Contributions from Boyce Thompson Institute, 17:57-86

Chhillar, B.S., Gulati, R. and Bhatnagar, P. 2007. Bioassay. In: Agricultural Acarology. Published by Daya Publishing House, New Delhi, 220-230.

Dewey, J. E. 1958. Utility of bioassay in the determination of pesticide residues. *Agricultural and Food Chemistry*, 6(4):274-281.

Durmuşoğlu, E., Hatipoglu, A., Gürkan, M.O. and Moores, G. 2015. Comparison of different bioassay methods for determining insecticide resistance in European Grapevine Moth, *Lobesiabotrana* (Denis &Schiffermüller) (Lepidoptera: Tortricidae). *Turkish Journal of Entomology*, 39(3):271-276.

Finney, D.J. 1952. Probit Analysis. 3rd ed. Cambridge, UK: Cambridge University Press, 1971.

Immaraju, J.A., Morse, J.G. and Brawne, O.L. 1990. Evaluation of three bioassay techniques for citrus thrips' resistance and correlation of the leaf dip method to field mortality. *Journal of Agricultural Entomology*, 1:17-27.

Paramasivam, M. and Selvi, C. 2017. Laboratory bioassay methods to assess the insecticide toxicity against insect pests-A review. *Journal of Entomology and Zoology Studies*, 5(3): 1441- 1445.

Potter, C. 1952. An improved laboratory apparatus for applying direct sprays and surface films with data on the electrostatic charge on atomized sprays. *Annals of Applied Biology*, 39:1-28.

Potter, C. 1941. A laboratory spraying apparatus and technique for investigating the action of contact insecticides with some notes on suitable test insects. *Annals of Applied Biology*, 28:142-169.

Regupathy, A. and Dhamu, K.P. 2001. Statistics workbook for insecticide toxicology, Softeck Computers, Coimbatore, Tamil Nadu, 1-206.

Siqueira, H.A.A., Guedes, R.N.C. and Picanço, M.C. 2000. Insecticide resistance in populations of *Tuta absoluta* (Lepidoptera: Gelechiidae). *Agricultural and Forest Entomology,* 2:147-153.

Sun, Y.P. 1963. Bioassay-Insects. In: Principles, methods and general applications-volume 1 in Analytical methods for pesticides, plant growth regulators and food additives (Eds. Gunter Zweig), Published by Elsevier, 1963; 399- 423.

T.V. Prasad. 2019. Handbook of Entomology. 4th ed. New Vishal Publications, New Delhi, Giriraj Printers, 2019.

Chapter - 8

Label Claim and Labeling of Pesticides

C.G. Sawant, L.D. Sharma, Rahul Sadhukhan and Rojeet Thangjam

Introduction

Climate change-driven global warming affects the annual rainfall, prolonged periods or shortfalls of rainfall, constant cloudy atmosphere, increased temperature, the intensity of lights, and relative humidity. Besides this, changed cropping pattern, monoculture of the same variety of particular crop, application of same crop management practices, etc., leads to farmers facing many problems related to insect pests. Resurgence or outbreak of secondary pests and developed resistance causing an increased number of application of pesticides against major or minor pests is now becoming a serious problem. Ultimately this leads to an increase in the cost of cultivation of the crop. Now it is time to move towards the good agricultural practices by the agricultural growers to produce quality fruits, vegetables, cereals, and pulses for an export purpose and the quality food supply to consumers of our country. Farmers use a substantial amount of pesticides throughout crop growth and sometimes even at the fruiting stage. Indiscriminate use of pesticides, particularly during the fruiting stage and non-adoption of a safe waiting period, results in the accumulation of residues in consumable fruits and vegetables.

Moreover, the produce is harvested at a short interval and consumed fresh. Therefore, it is unwise to use chemical insecticides alone to manage insect pests. An insecticide should be effective and economical, but should not leave toxic residues.

Any approved insecticide must remain active after its application on a crop or soil sufficiently long to protect target pests and yield economically viable produce. However, insecticides should dissipate to safe toxicological levels when a man needs the produce from the treated crop for consumption. Because of this hard reality, it is essential to study the concept of label claim and labeling of pesticides and their Importance to produce good income and for residue-free quality fruits and vegetables.

Although most of the dangers from unregulated and indiscriminate use of pesticides were brought into focus as early as in the year 1958 when the Government of India appointed a Commission of inquiry to suggest Inter-alia remedial measures following several deaths in Kerela and Madras (Tamil Nadu) by poisoning through the consumption of imported wheat contaminated by pesticide accidentally which was shipped together with food grains, the whole question of pesticide use and legislation was studied in 1964-67 by an Expert Committee of Indian Council of Agricultural Research headed by Prof. M.S. Thacker. Based on the recommendations of the Expert Committee, a comprehensive Insecticides Act was passed in 1968 to regulate the import, manufacture, sale, transport, distribution, and use of insecticides to prevent risks to human beings and animals and for other matters connected in addition to that. Under Section 4 and 5 of the Insecticide Act 1968, the "Central Insecticides Board and Registration Committee (CIB & R.C.)" has established the following objective.

1. The Central Insecticides Board advises the Central Government and State Governments on technical matters arising out of the administration of this Act and to carry out the other functions assigned to the board by or under Insecticide Act 1968.
2. The matters on which the board may advise includes :

a. The risk to human beings or animals involved in the use of insecticides and the safety measures necessary to prevent such danger.
b. The manufacture, sale, storage, transport and distribution of insecticides with a view to ensure safety to human beings or animals.

3. To register insecticide after scrutinizing their formulae and verifying claims made by the importer or the manufacturer, as the case may be, as regards their efficacy and safety to human beings and animals; and
4. To perform such other functions as are assigned to it by or under Insecticide Act 1968.

What is Label Claim and Labelling

Pesticide may be defined as any substance or mixture intended for preventing, destroying, repelling, or mitigating any pest and any substance or mixture intended for use as a plant regulator, defoliant, or desiccant. Pesticide is a broad term and etymologically which means pest (pests are organisms that cause crop losses, for example, insect, weeds, fungi, bacteria, viruses, nematodes, rats, mollusc, etc.) and cide (means which kills). Pesticides are classified into insecticides, fungicides, bactericides, weedicides, molluscicide, rodenticides, nematicides, etc.

Any pesticide manufacturers or companies registered under CIB & R.C. need to produce all the scientific data related to bio-efficacy, toxicity, residues, and safe waiting period obtained from a laboratory study. They need to conduct field trials with good agricultural practices (GAP) at their instructional farms and at various locations across the country in multiple seasons based on agro-climatic zones, i.e., multilocation field trials. While conducting multilocation field trials, various agricultural departments, research stations, multi-technology testing centers, and central and state agricultural universities are getting involved by registered pesticide manufacturers or companies. Besides this data related to safety to the birds, mammals, fish, humans, etc. and overall safety to the environment needs to produce to CIB & R.C. After collecting all the scientific data, a committee of CIB & R.C. thoroughly inspects and studies it to approve legal permission or approval for marketing and use of pesticides. Based on the pesticide residue data generated by conducting over 2500 multilocation supervised field trials following GAP in different agro-climatic zones of India, 115 label claims and safe waiting periods on the various pesticide-crop combinations have been approved by CIB & R.C. for their commercial use in the country during 2018-2019. Such permitted or approved pesticides are said to be label claimed and can be recommended to the farmers. It is a necessity to give detail written information of product over or in packing of the product. Manufacturers are required to provide information regarding what the pesticide is to be used for, how it can be used, how toxic it is, how to mix it, rate of application, precautions to take, re-entry times, kind of clothing, and personal protective equipment needed, what the antidote is (if any), and the symptoms of poisoning if exposed to the pesticide. Other information about the pesticide use, storage, handling, or disposal may also be found on the label.

According to Guidelines of Good Labeling Practice for Pesticides (FAO, Rome, March 1985), "A label is the written, printed or graphic material firmly attached to a container" This coincides with the definition given in: "Pesticides" (Council of Europe, Strasbourg, 6th Edition, page 119). The "International Code of Conduct on the Distribution and Use of Pesticides," adopted by the FAO Conference on 28 November 1985, extends the above definition as "any written, printed, or graphic material that is attached to a pesticide or written, printed or attached to its immediate container or included in the package or outer wrapping for use or retail distribution." In India, the "Central Insecticides Board and Registration Committee (CIB & R.C.)" regulates and monitors all the scientific and legal aspects of pesticides approval, from preparation or manufacturing to labeling with the objectives mentioned above. The pesticide label is the information approved by the CIB and RC to comply with all instructions and use directions provided on the pesticide container/leaflet for safe and judicious use of the product. Pesticide labels contain detailed information on how to use the product correctly and legally.

Benefits and importance of label claim

1. Farmers will get legal assurance, guarantee, and protection related to the quality of product or pesticides they are using.
2. The label claimed products or pesticides are legally approved, so they can safely recommend to farmers.
3. The label claimed products or pesticides are legally approved after verifying all the laboratory and field results of their toxicity to the birds, mammals, fish, humans, etc. It then declared as safe to not only animals but the environment also.
4. Farmers will know about the Post Harvest Interval (PHI) period of particular products or pesticides for a specific crop which will help get the Maximum Residual Limit (MRL) of pesticides in fruits and vegetables.
5. The label claimed products or pesticides are also safe for crops, so they will not show any effects of phytotoxicity.
6. Label claims can be helpful to avoid the misguidance, misbranding, and fraud of pesticides against farmers by restricting the recommendations of non-label claimed pesticides.

Importance of label and labeling

Pesticide labels are legal documents on the container that gives the user information about the product. The product label tells the purchaser and user:

1. Kind of pesticide, brand name, and common name.
2. Who is manufactured or supplied the product?
3. Registration number of insecticide.
4. What type and degree of hazard it presents.
5. What kind of formulation and active ingredients are used.
6. Date of expiring.
7. What to do if adverse effects occur/antidotes.

Failure to display mandatory warning or caution on labels of pesticides product is defined as "misbranding" under Sec 3 (k) (iii) and is liable to be prosecuted for an offense under Sec 29 (1) (a) of the Insecticides Act, 1968.

Manner of Labeling

The following particulars shall be either printed or written on the label of the innermost container of any insecticide and on the outermost covering in which the container is packed:

1. Name of the manufacturer (if the manufacturer is not the person whose name the insecticide is registered under the Act, the relationship between the person whose name the insecticide has been registered and the person who manufactures, packs, or distributes, or sells shall be stated).

a. Name of insecticide (brand name or trademark under which the insecticide is sold).

b. Registration number of the insecticide.

c. Kind and name of active and other ingredients and percentage of each. (Common name accepted by the International Standards Organization or the Indian Standards Institutions of each of the ingredients shall be given. If no common name exists, the correct chemical name that conforms most closely with the generally accepted rules of chemical nomenclature shall be given be provided).

d. The net content of the volume. (The net contents shall be exclusive of wrapper or other material. The correct statement of the net content in terms of weight, measure, number of units of activity, as the case may be, shall be given. The weight and volume shall be expressed in the metric system).

e. Batch number.

f. Expiry date, i.e., up to the date the insecticide shall retain its efficiency and safety.

g. Antidote statement.

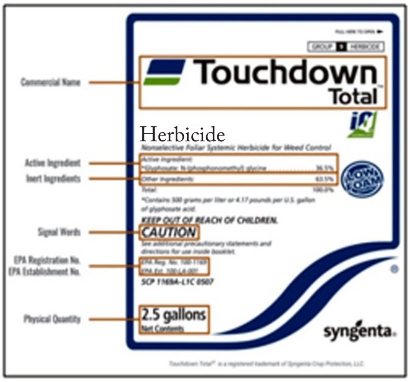

Fig. 8.1 Information is written on the pesticide container

2. The label shall be so affixed to the containers that it cannot be ordinarily removed.

3. The label shall contain in a prominent place and occupying not less than one-sixteenth of the total area of the face of the label, a square, set at an angle of 45^0 (diamond shape). The dimension of the said square shall depend on the size of the package on which the label is to be affixed. The said square shall be divided into two equal triangles; the upper portion shall contain the symbol and signal word as specified, and the lower portion shall contain the color specified.

4. The upper portion of the square shall contain the following symbols and warning statements.

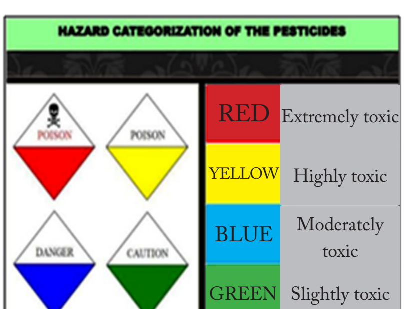

Fig. 8.2 Pesticide categories and label/leaflet on pesticide package

a. Insecticides belonging to Category I (Extremely toxic and red color) shall contain the symbol of a skull and cross-bones and the word "POISON" printed in red. The following warning statements shall also appear on the label at the appropriate place, outside the triangle,

i. "Keep out of the reach of children."

ii. "if swallowed, or if symptoms of poisoning occur, call the physician immediately."

b. Insecticides in Category II (Highly toxic and yellow color) will contain the word "POISON" printed in red and the statement "keep out of the reach of children"; shall also appear on the label at the appropriate place, outside the triangle.

b. Insecticides in Category III (moderately toxic and blue color) shall bear the word "DANGER" and the statement "Keep out of the reach of children"; shall also appear on the label at a suitable place outside the triangle.

c. Insecticides in Category IV (Slightly toxic and green color) shall bear the word "CAUTION" in the lower portion of the square.

5. In addition to the precautions to be undertaken, the label to be affixed in the package containing highly inflammable insecticides shall indicate that it is inflammable or that the insecticides should be kept away from the heat or open flame-like.

6. The label to be affixed or attached to the package containing insecticides shall be printed in Hindi, English, and in one or two regional languages in use in the areas where the said packages are likely to be stocked, sold, or distributed.

7. Labeling of insecticides must not bear any unwarranted claims for the safety of the producer or its ingredients. This includes statements such as "SAFE," "NON-POISONOUS," "NON-INJURIOUS," or "HARMLESS" with or without such qualified phrase as "when used as directed."

Leaflet

In some instances, the pesticide package may include a leaflet indicating the information on the label or containing mandatory information that should have been on the label but was omitted because of the limited size of the container. It may also happen that the products concerned require more detailed information as to their use, and the space on the container is insufficient rather than make the label illegible by reducing print size, label information may be presented on the container and a separate leaflet. When a leaflet is used, "READ THE ATTACHED LEAFLET BEFORE USING THIS PRODUCT," this statement must appear in bold capital letters on the main panel of the container label. It should also be pointed out that, in every case, hazard symbols, product name, safety precautions, first-aid instructions, and the name and address of the manufacturer, distributor, or agent must appear on the leaflet as well as on the container, so the user can easily match the two separate components of the label.

Leaflet information

The packing of every insecticide shall include a leaflet containing the following details, namely;

1. The plant disease, insects, and noxious animals or weeds for which the insecticide is to be applied, the adequate direction concerning the manner in which the insecticide is to be used at the time of application;
2. Particulars regarding chemicals harmful to human beings, animals, and wildlife, warning and cautionary statements including the symptoms of poisoning suitable and adequate safety measures and emergency first-aid treatment where necessary;
3. Cautions regarding storage and application of insecticides with suitable warnings relating to flammable, explosive, or other substances harmful to the skin;
4. Instructions concerning the decontamination or safe disposal of used containers;
5. A statement showing the antidote for the poison shall be included in the leaflet and the label;
6. If the insecticide is irritating to the skin, nose, throat, or eyes, a statement shall be included to that effect.
7. Common name of the insecticide as adopted by the International Standards Organization and where such a name has not yet been adopted such other name as may be approved by the Registration Committee.

References

https://aicrp.icar.gov.in

Insecticides Rules, 1971. Packing and Labeling. https://www.medindia.net/indian_health_act/insecticides-rules-1971-packing-and-labelling.htm.

Luis Gonzalez Vaque. 1998. Pesticide labeling legislation, FAO, United Nations, pp 12-18.

Manual for Certificate Course on Plant Protection & Pesticide Management (for Pesticide Dealers) by NIPHM, Hyderabad.

Press Information Bureau. 2015. Label on Pesticides Products, Government of India, Ministry of Agriculture & Farmers Welfare. https://pib.gov.in/newsite/PrintRelease.aspx?relid=124297.

www.ppqs.gov.in

Chapter - 9

Pesticide Regulations and Food Laws

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Introduction

The use of pesticides has increased because of the increasing demand for agricultural crops and decreasing availability of agricultural lands (Pham *et al.*, 2016, Uram, 1990). Pesticides are widely used in agriculture to reduce and eradicate insect pests and diseases. While cultivating the soil and increasing crop production to meet the emerging demand of the growing population, herbicides, insecticides, fungicides, nematicides, fertilizers, and soil amendments are now being used in higher quantities than in the past. However, indiscriminate use and improper handling of synthetic pesticides in agriculture may cause severe problems to human health, especially among farmers and farm workers (Calvert *et al.*, 2004, Dasgupta *et al.*, 2007). The various deleterious impacts that arise by acute or chronic pesticide poisoning may vary according to the chemical structure and affinity of pesticides, pesticide quantity and frequency of its use, route of exposure to pesticides and pesticide residues, and organ system, age, economic condition, and education level of the victims (Pronczukd, 2008). Entry of pesticides into the human body may occur via various routes such as ingestion, inhalation, dermal absorption, or ocular contact.

Globally, there is a significant concern about the harmful impacts of pesticides and their residues on human health and the surrounding environment. Developing countries like India bears a massive share of the poisonings and deaths rates caused by pesticides and their residues, mainly because of misuse of pesticides, poor regulation, lack of surveillance systems, less enforcement of laws and regulations, lack of training and awareness among users, and inadequate access to information systems. There are limited or no appropriate personal protective gears for the pesticide users and applicators (Pronczukd, 2008, FAO, 2003). Developed countries also suffer from pesticide poisoning because of exposure to pesticides and their residues. The drastic use of pesticides by the developed countries may contaminate water reservoirs and food chains with pesticide residues (Norris *et al.*, 1992). Problems associated with pesticide use have given recognition to the need for protection from pesticide exposures and reconsideration of pesticide use practices (Dasgupta *et al.*, 2007, Calvert *et al.*, 2008). The United Nations Food and Agricultural Organization (FAO) formulated the International Code of Conduct (1985) on distribution and application of pesticides to bring harmony among pesticide exporting and importing countries (Uram, 1990, Ecobichon, 2001).

At present, many countries have regulatory agencies and institutes responsible for implementing laws and regulations to control and monitor the usage of pesticides. However, there is still a lack of coordination among regional organizations. Countries from the same region have similar legislation with almost identical aims and objectives; therefore, synchronizing all the existing laws into a single regional framework and compiling a regional database can prove beneficial.

Food may be in solid or liquid form, is consumed to provide energy and nutrition to the body. It should be wholesome and not have harmful substances such as pesticide residues. The food should be in the natural form with its property and grade of excellence. Pesticides may be applied while the crop is in the field to free from insect pests and attractive texture, while the Pesticides and their residues might also have a detrimental effect on the consumers' health. The additives added in processed foods should also be monitored to safeguard the consumers' health. The quality parameters are the grades, standards, and specifications laid down by the government agencies or expert bodies constituted for this purpose.

Regulations on Pesticides at Global Level

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 the 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) (Uram, 1990, Ecobichon, 2001). The fundamental purpose of this code was to bring harmony among industrialized pesticide exporting countries and pesticide importing countries. Before this code, there was a concern that different pesticides banned in their country of origin were exported to developing countries, which lacked the legal, technical, and administrative resources to access pesticide toxicity in various food products (Uram, 1990). The code provides a Prior Informed Consent (PIC) portion, which aids the importing country with information concerning the imported pesticides (Ecobichon, 2001). However, the code is solely voluntary and legally non-binding; the code was designed to act as an interim measure until local governments developed adequate regulations (Uram, 1990, Ecobichon, 2001).

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

The objectives of the Rotterdam Convention are

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

As per the regulations of the Rotterdam Convention, importing countries can make well-informed decisions by analyzing the "Import Responses Form" for a particular pesticide. They can also verify the list of pesticides and industrial chemicals banned or restricted for health or environmental concerns by various countries. In addition, parties or countries can report and check relevant causes and impacts of pesticide poisoning through Severely Hazardous Pesticide Formulations (SHPF) Forms.

Rotterdam Convention includes two significant conventions. The first one is The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, which came into effect in 1992, aimed to reduce the movement of hazardous waste between different nations. The second one is The Stockholm Convention on Persistent Organic Pollutants, which came into effect in 2004, aimed to reduce the production and use of persistent organic pollutants (POPs) (Basel Convention, 1989, Stockholm Convention, 2001).

One crucial initiative for pesticide management is the FAO/WHO Joint Meeting on Pesticide Management (JMPM) and the 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 from the point of manufacturing to the safety use. The annual meeting advises FAO and WHO on pesticide regulation and management and helps them implement the International Code of Conduct on Pesticide Management (FAO/WHO, 2010 and 2013). The WHO classifies existing pesticides according to their toxicity and provides guidelines for future classification (WHO, 2009). The Codex Pesticides Residues in Food Online Database is an important database containing the Maximum Residue Limits (MRL) and Extraneous Maximum Residue Limits (EMRL) for the pesticides adopted by the Codex Alimentarius Commission, 2013. Based on the above discussion, it may 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 can curtail the harmful effects of pesticides.

Regulations on pesticides in India

In India, regulations on pesticides are governed by two central agencies, the Central Insecticides Board and Registration Committee (CIB & RC) and the Food Safety and Standards Authority of India (FSSAI). CIB & RC was established in 1968 by the Ministry of Agriculture and Farmers Welfare. It is responsible for advising the central and state governments on technical issues related to manufacturing, use, and pesticides safety. Its responsibilities also include recommending uses of various types of pesticides depending on their toxicity and suitability, determining the shelf life of pesticides, and recommending a minimum gap between the pesticide applications and harvesting of the crops (waiting period). The other part of the Central Insecticides Board, the registration committee, is responsible for registering pesticides after verifying the claims of the manufacturer or importer related to the efficacy and safety of the pesticides. The second central agency is the Food Safety and Standards Authority of India (FSSAI). The FSSAI was established by the Ministry of Health and Family Welfare under the Food Safety and Standards Act, 2006, responsible for recommending tolerance limits of various pesticides in food commodities. The State Agriculture Universities (SAUs), State Agriculture Departments (SADs), and other institutions related to specific crops like the National Horticultural Board (NHB) and Spices Board of India make another set of recommendations for agricultural practices, including the use of pesticides (CSE, 2013).

The harmful effects of pesticides are now becoming a serious concern facing various countries worldwide. The harm caused may be in terms of acute or chronic. Farmers and agricultural workers are the direct users of pesticides and are more likely to get affected by the acute toxicity of pesticides. The chronic toxicity gradually affects the whole population of those in contact directly or indirectly with the pesticides. After use, the residues left in the harvested fruits, vegetables, cereals, pulses, soil, and water are translocated into the human food chain. Intake of pesticide residues through food and water has been linked to congenital disabilities, toxicity to the fetus, cancers, genetic defects, blood disorders, neurotoxicity, and endocrine disruption (CSE, 2013).

In 2003, a Joint Parliamentary Committee (JPC) was formed after The Center for Science and Environment (CSE), a non-governmental organization based in New Delhi, released its report on pesticides in carbonated beverages of various brands. The JPC was formed to verify the CSE's results and suggest the criteria for evolving suitable safety standards for soft drinks, fruit juice, and other beverages where water is the main constituent. The committee came up with various recommendations about the residue limits in beverages, fruits, juices, and drinking water and pesticides regulations in India (CSE, 2013).

Recommendations of the Joint Parliamentary Committee (JPC)

There were several laws and many ministries at that time looking after the issue of food safety. The committee recommended the formation of Food Safety and Standards Authority of India to make one single authority to deal with food safety issues (CSE, 2013).

» The committee recommended that standards for carbonated beverages best suited for the Indian conditions need to be fixed in the overall perspective of public health.

» The committee noted that daily intake of various foods had not been established, which could decide the intake rate of pesticides. The committee recommended collaborative research with premier institutions in the country involved in the total exposure to pesticides.

» The committee also recommended proper monitoring of groundwater to check the depletion in its level and its quality.

» The committee noted that fruit juices couldn't be clubbed with carbonated beverages. It recommended separate MRLs for these two products.

» The committee also recommended that institutions like the Indian Council of Medical Research (ICMR), National Institute of Nutrition, and Central Food Technological Research Institute (CFTRI) should evolve database taking into account our food habits concerning the consumption of processed and non-processed food, level of contaminants, and pesticides in these food products, their conformity with acceptable daily intake, usage of pesticide in agriculture and public health programme based on their database.

» The committee desired that the data for the registered pesticides should be completed, and accordingly, MRLs for all the pesticides should be set.

» The committee recommended a review of MRLs existing to check their compliance to the Acceptable Daily Intakes (ADI). The process should be repeated with any scientific development in the field. In case daily intakes exceed ADI for pesticides, the MRLs should be reset.

» The committee recommended completing data on all pesticides, including registered pesticides, for their residues in the products they are applied to and accordingly setting the waiting periods. The farmers were to be educated about waiting periods.

» The committee recommended the Ministry of Health and Family Welfare and Ministry of Agriculture to check the uses of restricted pesticides like Lindane and DDT for agricultural purposes.

» The committee recommended strict punishment for people indulging in selling banned and restricted pesticides.

» The committee also recommended monitoring of pesticides in various products every year.

» The committee also recommended aggressive awareness programmmes for farmers and promoting the use of bio-pesticides. It suggested promoting research and development to explore the biodiversity of India for more eco-friendly pesticides. Promoting organic farming was also recommended.

Eight years after the committee submitted its report, it is essential to analyze India's current pesticides regulations regarding food safety.

Regulations of PFA on Maximum Residue Levels (MRLs)

Maximum Residue Limits (MRLs) are the maximum residues of pesticides, which may be expected in a product treated with them, considering that Good Agricultural Practices have been followed. Acceptable Daily Intake (ADI) is the maximum intake of pesticide that can be tolerated from all dietary sources in a day without posing any chronic health risk. Theoretical Maximum Daily Intake (TMDI) estimates the maximum intake of the pesticide with the existing MRLs for a person following a particular dietary practice. Good Agricultural Practices (GAP) have been defined as "practices that address environmental, economic and social sustainability for on-farm processes, and result in safe and quality food and non-food agricultural products" by the Food and Agriculture Organization4. In India, the Bureau of Indian Standards (BIS) adopted the 'Requirements for Good Agricultural Practices' in 2010. It recommends practices for every stage of farming, from land preparation to the post-harvest supply chain.

The Ministry of Health and Family Welfare regulates MRLs of pesticide and agrochemical in food products through the Prevention of Food Adulteration Act (PFA), 1955 as amended. However, with the Food Safety and Standards Act (FSSA), 2006, the PFA rules are being phased into the Food Safety and Standards Regulations, 2010. The new Act authorizes the Food Safety and Standards Authority of India (FSSAI) to "specify the limits for the use of food additives, crop contaminants, pesticide residues in fruits and vegetables, residues of veterinary drugs, heavy metals, processing aids, mycotoxins, antibiotics, and pharmacologically active substances and irradiation of food." The existing MRLs on pesticides and agrochemicals specified in the PFA are incorporated in the Food Safety and Standards Regulations, 2010. MRLs are listed by chemical products for specific food items/commodities. However, in some cases, tolerance limits are established for more generic food categories (i.e., for Carbaryl, "other vegetables" have an MRL of 5.0 parts per million (Gain report. 2011).

Regulations on use of pesticides/agrochemicals

The Ministry of Agriculture and Farmers Welfare regulates the manufacture, sale, import, export, and use of pesticides through the Insecticides Act, 1968 and the Insecticides Rules, 1971. All pesticides such as insecticides, fungicides, acaricides, rodenticides, and herbicides are listed by a particular company or manufacturer must undergo a registration process with the Central Insecticides Board & Registration Committee (CIB&RC). Till 2020 there are 292 pesticides registered under Section 9(3) of the Insecticides Act, 1968. Registered pesticides must be clearly labeled to indicate composition, active ingredient(s), target pest(s), recommended dosage, agricultural or household use, as well as any cautionary safety information. Besides, CIB & RC States and Union Territories of the country have the authority to grant licenses for the manufacture and sale of insecticides. In addition, state officials work with the CIB&RC to conduct analysis (including MRLs of the pesticide post-harvest), to report and enforce on matters of public safety. The CIB&RC periodically reviews pesticide usage and sometimes recommends bans on registration (e.g., when the MRLs are found to be above the PFA limits in agricultural produce post-harvest) (Gain report. 2011).

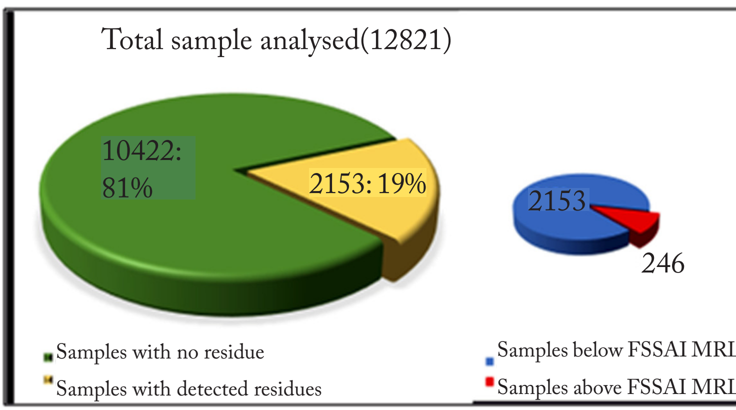
Setting up of MRL's

The Medical Toxicological Unit of CIB & RC works closely with the Ministry of Health and Family Welfare and the Food Safety and Standards Authority of India (FSSAI) to set MRLs, which are subsequently included in the Food Safety and Standards Regulations. The Ministry of Agriculture and CIB & RC has indicated that it would not approve new insecticide registrations without established MRLs. Pesticides Management Bill was passed in 2020, and this new law repealed the Insecticides Act, 1968, and will establish a more direct linkage between pesticide registration and the establishment of MRLs. Section 12(5) of the Bill proposes that "no pesticide shall be registered for import or manufacture unless its tolerance limits are specified for its residues on fruits and vegetables and commodities under the Food Safety and Standards Act, 2006." In the absence of an established MRL, the Ministry of Health authorities generally refer to CODEX Alimentarius MRLs, as long as the pesticide in question has not been banned (Gain report. 2011).

Regulation of food products for MRLs

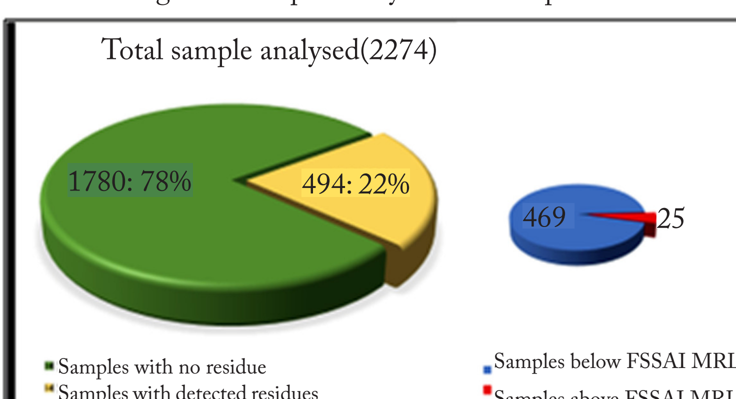
All food products sold in India must comply with the MRLs established in the PFA/ Food Safety Standard Regulations for all the approved insecticides and agrochemicals. The FSSAI and state-appointed inspectors have the authority to test products, both essential commodity and processed food products, for adherence to the MRLs. If products are found to be non-compliant, inspectors can take punitive action against the processor/trader/ retailer. Imported food products must also comply with MRLs established by the PFA, 1955 as amended Food Safety and Standards Regulations, 2010. At the Port of entry, Customs authorities work with FSSAI nominated officials to sample and test compliance with the PFA/ Food Safety Standard Regulations, including MRLs. FSSAI has designated laboratories for testing. Upon evaluation of the sample, Customs authorities can proceed with clearing the consignment for entry into India. Importers can request a retesting of the result and can submit an appeal to FSSAI authorities. However, if a product is non-compliant with the PFA/ Food Safety Standard Regulations, it will refuse entry into India. In 2006, the Ministry of Agriculture initiated a program to monitor pesticide residues at the national level. Working through the Indian Council of Agricultural Research, the Ministry selected 20 laboratories to collect and analyze vegetables, fruits, spices, pulses, cereals, milk, fish, tea, honey, meat, animal feed, and groundwater. In the case of food grain, fruits, vegetables, dry fruits, tree nuts other essential commodities, the Ministry of Agriculture works through the Plant Quarantine Office at the Port to test for the presence of banned pesticides and agrochemicals (Gain report. 2011).

During 2017-18, under the Department of Agriculture & Farmers Welfare, Ministry of Agriculture & Farmers Welfare sponsored central sector scheme, "Monitoring of Pesticide Residues at National Level," 27 NABL accredited participating laboratories located in different parts of India collected and analyzed the samples of vegetables and fruits for the possible presence of pesticide residues.



(Source: - FSSAI, 2019)

Fig 9.1 Number of vegetable samples analyzed and samples with detected residues



(Source: - FSSAI, 2019)

Fig 9.2 Number of fruit samples analyzed and samples with detected residues

Adulteration of Food : Another Primary Concern

It is mainly practiced in India by traders to get the maximum quantity for a price as low as possible. This condition is common in India because consumers like to get more amounts for a lower cost while the sellers, to exist, must meet the needs of the buyers. When the price of the food product is higher than the price the consumer is willing to pay, the seller is compelled to supply a food product of inferior quality, and thus adulteration starts. It might be intended by the wilful Act by adulterator to increase the margin of profit or unintentionally by ignorance, negligence, or lack of proper facilities. Adulteration in food items can have a tremendous effect on health without our knowledge (Ameeta *et al.*, 2017)

Food Laws

Food laws in a country should be considered a welcome step to encourage the scientific development of the industry. Food laws and control systems in any country help safeguard the interests of the consumer in two respects: a) safety in the health hazards that may arise on account of adulteration, contamination of pesticides and its residues, microbiological deterioration, decay, and other factors and b) to protect the pocket of a consumer to ensure fair trade practices in articles of food. The food laws thus help to prevent the loss of foods to a large extent that may occur through unhygienic storage conditions, handling, transport, and so on. Food laws should look to the country's nutritional requirements wherever necessary; food standards for a food product should lay down the minimum nutrients that are essential for a particular area or a country as a whole. Another significance of food laws is the prevention of dumping of substandard foods imported from other countries. On the other hand, it helps to earn foreign exchange by exporting foods of acceptable quality. Food is an item that could account for 50% or 60% of a family's budget, and thus, the Government must give some protection to the hard-pressed consumers.

Adulteration is a term used to determine whether a product is not what it should be, from a biochemical point of view and cleanliness and hygienic point of view. Consumers need to check and control the food marketed for human consumption for their health safety. When a substance is termed an 'adulterant,' more substantial penalties apply, including the possibility of criminal liability. Before they use the foods for consumption, consumers should be concerned about safety, wholesomeness, nutritional adequacy, palatability, and cost.

The food quality control problem in developing countries like India is quite different from other advanced or developed countries. For example, a farmer in a developed country always aims to increase nutritional value, aesthetic appeal, and freedom from extraneous and harmful contaminants. In developing countries, the concern is to prevent intentional adulteration, detecting and punishing unscrupulous traders and manufacturers.

In all the countries, there are government bodies to watch over food quality control by drafting policies and standards to lay down standard procedures for implementing the schemes to achieve the objective of prevention of adulteration. One of the first food laws passed in the Parliament was the Prevention of Food Adulteration Act, 1954 to promote food security in India.

In the process of cultivating the soil and increasing raw foods crop production to meet emerging demand, herbicides, insecticides, fungicides, nematicides, fertilizers, and soil amendments are now being used in higher quantities. Numbers of insect pests attack fruits and vegetables. To manage problems, farmers use a substantial amount of pesticides throughout crop growth and sometimes even at the fruiting and harvesting stages of crops. Indiscriminate use of pesticides, particularly during the fruiting stage and non-adoption of the safe waiting period, results in pesticide residues in foods, i.e., fruits, vegetables, cereals, pulses, eggs, meat, and fish. Many fruits and vegetables grown on sewage are prone to be contaminated with harmful microorganisms and hazardous metals, which are generally destroyed during cooking or food processing. At the same time, some may survive due to insufficient heat processing causing food poisoning, while some of the food, when consumed in a raw state, may cause food poisoning. Food poisoning means illness resulting from the ingestion of food with microbial or chemical contamination (Rajesh, 2017). The true incidence of foodborne diseases is unknown for many reasons, including poor responses from the affected person during health official visits, misdiagnosis of the illness, improper collection of samples for laboratory analysis, and improper laboratory examination. So, there is a need to implement strict food safety laws for giving punishment (fines, imprisonment, etc.) to persons found guilty of breaking the rules (Jagdish *et al.*, 2018).

Considering all food poisoning and toxic effects of pesticides and their residues and hazardous metals in the body and the environment, it becomes very urgent to regulate the food commodities for the safety of the consumer and the environment's well-being through the formulation of rules and regulations. Considering the harmful effects of adulteration, there are different agencies in all the countries that look after the quality work by formulating policies, framing standards, laying down standard procedures for implementing the schemes to achieve the objective of prevention adulteration.

The safety of food is a global issue in international trade and the public health sector. Governments worldwide are intensifying their efforts to improve food safety, which may be achieved effectively by legislative measures, certification schemes, and public participation and involvement in the program. Under the Ministry of Health and Family Welfare, the Central Government has established a body known as 'Food Safety and Standards Authority of India' to perform the functions assigned under 'The Food Safety and Standards Act.

This Act consists of various food-related acts as stated below:

1. Prevention and food adulteration act, 1954
2. Fruit products order, 1955
3. Meat food products order, 1973
4. Vegetable oil products order, 1947
5. Edible oils packaging (regulation) order, 1988
6. Solvent extracted oil, de-oiled meal and Edible flour (control) order, 1967
7. Milk and Milk products order, 1992

The Food Safety and Standards Authority of India lays down science-based standards for food articles and regulates their manufacture, storage, regulation, sale, and import to ensure the availability of safe and wholesome food for human consumption.

Food Safety and Standards Act

Food safety has emerged as a significant global issue. Many studies have been carried out on detecting pathogenic microorganisms, adulterants, and contaminants in food and concluded that protection of diets from these hazards must be considered very urgent for consumer safety by any country who emphasises the need for total diet studies (Sudershan *et al.*, 2009). Food Safety and Standards Act 2006 has become operational in India from 5th August 2011. This Act targets establishing a single reference point for all matters relating to food safety and standards by moving from multi-level, multi-departmental control to a single-like command. The study on food safety still lacks essential data and additional research techniques to understand and achieve behavioral change. Failure to do so will result in stubbornly high levels of foodborne disease (Christopher, 2006).

General principles of food safety

The Central Government, the State Governments, the Food Authority, and other agencies, as the case may be, will be guided by the following principles:

1. To endeavor to achieve an appropriate level of protection of human life and health and the protection of consumers' interests
2. To carry out risk management which shall include taking into account the results of risk assessment and other factors which in the opinion of the Food Authority are relevant to the matter under consideration
3. In any specific circumstances, the basis of assessment of available information, the possibility of harmful effects on health is identified. Still, scientific uncertainty persists, provisional risk management measures necessary to ensure an appropriate level of health protection may be adopted, pending further scientific information for a more comprehensive assessment.
4. The measures adopted basis on clause (c) shall be proportionate and no more restrictive of trade than is required to achieve an appropriate level of health protection, regard being had to technical and economic feasibility and other factors as reasonable and proper in the matter under consideration
5. To review the measures adopted within a reasonable time, depending on the nature of the risk of life or health being identified and the type of scientific information needed to clarify the scientific uncertainty and to conduct a more comprehensive risk assessment.
6. In cases where there are reasonable grounds to suspect that a food may be a risk for human health, then depending on the nature, seriousness, and extent of that risk, the Food Authority and the Commissioner of Food Safety shall take appropriate steps to inform the general public of the nature of the risk to health, identifying to the fullest extent possible the food or type of food, the risk that it may present, and the measures which are taken or about to be taken to prevent, reduce or eliminate that risk, and
7. Where any food which fails to comply with food safety requirements is part of a batch, lot, or consignment of food of the same class or description, it shall be presumed until the contrary id proved that all of the food in that batch, lot of consignment fails to comply with those requirements.

Food standardisation and regulation agencies in India

Central Committee for Food Standards (CCFS) is concerned with preventing food adulteration and fraudulent practices. In 1957, it was functioning to advise the central and state Government on matters arising out of the administration of the Food Safety and Standards Act provide guidelines for

» Minimum basic requirements of food quality during handling, storage, preparation, and serving of food under sanitary conditions.

» Freedom from extraneous matter, foreign matter, impurities, and mixed materials

» Proper packaging branding and declaration of net wages as well as dates of manufacturing and packing

The guidelines are primarily intended to protect consumers from the health hazards of poisoning food and exploitation by malpractice such as misbranding, adulteration, incorrect labeling, false claims, less weight, excessive and indiscriminate use of food additives, etc.

Central Food Laboratories (CFL)

The Government of India established four central food laboratories serving as appellate laboratories for analysis of food supplies. These are

1. Central Food Laboratory, Kolkata, West Bengal
2. Food Research and Standardisation Laboratory, Ghaziabad, Hariyana
3. Public Health Laboratory, Pune, Maharashtra
4. Central Food Technological Research Institute Laboratory, Mysore, Karnataka

In addition to these, every state has established its food analyzing laboratories in their states.

International Standards

1. International Organisation for Standardisation (ISO)

The main objective of ISO is the promotion of the development of standards in the world to facilitate a global exchange of goods and services and to develop cooperation in the sphere of intellectual, scientific, technological, and economic activity.

2. Codex Alimentarius

It was established in 1962. It means ‘Food Law’ or ‘Food Code’ in Latin which means a combination of standards, codes or practices, and other model regulations available for countries to use and apply to food in international trade. The dual objectives of the Codex Alimentarius Commission are to protect consumers’ health and facilitate international trade. It is based on the principles of sound scientific analysis and evidence so that the standards assure the quality and safety of the food supply. Codex has provided guides for good agricultural practices, including using pesticides, commodity food standards for processing products, and hygiene codes for making food safe for food manufacturing.

The Codex Secretariat is located in Rome and is financed by the FAO and the WHO. Presently there are 165 countries, including India, and covers 98 % of the world's population. The codex commission meets every two years, either in Rome or in Geneva.

3. Hazard Analysis Critical Control Point (HACCP)

HACCP is a food safety risk management tool that is applied to determine significant hazards of specific products and processes and to control the occurrence of such threats. HACCP is a change from traditional methods reliant on end-product testing to determine if the product is safe. It is preventive in its approach while it aims to prevent rather than detect problems.

In India, HACCP certification has been made compulsory for seafood export-oriented units. The Indian experience indicates that it would be possible for developing Asian countries to adopt HACCP measures. However, they need to be evolved locally by each unit and strictly implemented rather than relying on certification. The Codex Alimentarius Commission has recognized the HACCP system as a tool to ensure the safety of food products. Quality Council of India launched two Certification schemes viz., 'India GHP' and 'India HACCP' based on globally accepted Codex Standards for adoption by food manufacturers and supply chain operators, which will help India food chain related industry to demonstrate compliance to global standards without having to go for costly and time consuming foreign certifications as many countries have mandated HACCP for high-risk sectors like meat, fish, dairy, etc. and most developed countries also have mandated good Hygienic Practices (GHP) across all food sectors. Ministry of Food Processing Industries of India provides Grant-in-aid in the form of reimbursement of expenditure towards implementation of HACCP/ISO Standards/Food Safety/Quality Management System @50% in the general area and 75% in North East Region and challenging areas of the eligible project cost subject to a maximum of Rs. 17 lakh and 22 lakh respectively.

Conclusion

All the organizations, at the national and international levels, should work together to ensure the safety of the consumer while trying to maintain food security. Foods available should be safe and not toxic for consumption. Emphasis should not only be given to profit in the food industry but the safety of consumers should be given the most important criteria in any food business, which can be ensured only when the various lawmakers on food perform their functions honestly and regularly to provide safe foods. There are international codes of conduct and conventions to promote shared responsibilities and cooperative efforts among countries. Different countries also have specific laws and regulations to regulate pesticide management. Combining existing laws into a single regional framework and compiling a regional database can prove beneficial for countries from the same region.

Reference

Ameeta, Sharma., Neha, Batra., Anjali, Garg and Ankita, Saxena. 2017. Food Adulteration: A Review. *International Journal for Research in Applied Science & Engineering Technology*, 5(3): 686-89.

Basel Convention. 1989. Available from: http://www.basel.int/TheConvention/Overview/tabid/1271/Default.aspx

Calvert, Geoffrey, M., David, K., Rupali, Das., Rachel, Rosales., Omar, Shafey., Catherine, Thomsen., Dorilee, Male., John, Beckman., Ernest, Arvizu and Michelle, Lackovic. 2004. Acute occupational pesticide-related illness in the US, 1998–1999: surveillance findings from the SENSOR-pesticides program. *Am. J. Ind. Med.,* 45(1), 14–23.

Calvert, Geoffrey, M., Jennifer, Karnik., Louise, Mehler., John, Beckman., Barbara, Morrissey., Jennifer, Sievert., Rosanna, Barrett., Michelle, Lackovic., Laura, Mabee., Abby, Schwartz., Yvette, Mitchell. and Stephanie, Moraga-McHaley. 2008. Acute pesticide poisoning among agricultural workers in the United States,1998–2005. *Am. J. Ind. Med.,* 51(12), 883–898.

Christopher, J. G. 2007. Food safety: where from and where to? *British Food Journal,* 108(1): 6-15.

Codex Pesticides Residues in Food Online Database. 2013. Available from: http://www.codexalimentarius.org/standards/pesticide-mrls/.

CSE. 2013. State of pesticide regulations in India. https://www.cseindia.org/state-of-pesticide-regulations-in-india-7611.

D. J. Ecobichon. 2001. Pesticide use in developing countries. *Toxicology,* 160, 27–33.

Dasgupta, Susmita., Craig, Meisner., David, Wheeler., Khuc, Xuyen., Nhan, Thi, Lam. 2007. Pesticide poisoning of farmworkers–implications of blood test results from Vietnam. *Int. J. Hyg. Environ. Health*, 210(2), 121–132.

FAO. 2003. International code of conduct on the distribution and use of pesticides (WHO and FAO, Rome, 2003)

FAO/WHO. 2010. The 4th FAO/WHO Joint Meeting on Pesticide Management (JMPM) and the 6th Session of the FAO Panel of Experts on Pesticide Management (FAO/WHO, Geneva, 2010)

FAO/WHO. 2013. The 7th FAO/WHO Joint Meeting on Pesticide Management (JMPM) and the 9th Session of the FAO Panel of Experts on Pesticide Management (FAO/WHO, Geneva, 2013).

FSSAI. 2019. Monitoring of Pesticide Residues at National Level. File No. 7(5) 2019/Pesticide residues/ RCD/FSSAI.

Gain report. 2011. Regulations on Maximum Residue Levels of Pesticide and Agro-Chemical, GAIN Report Number: IN1104.

http://www.fao.org/prods/gap/

https://globalfoodsafetyresource.com/food-adulteration

https://mofpi.nic.in/Schemes/food-safety-quality-assurance infrastructure/implementation-haccp-iso-22000-iso-9000-ghp-gmp-etc

https://ssrana.in/corporate-laws/food-laws/

Jagdish, K. A., Inchulkar, S.R., and Sangeeta, B. 2018. A review on Food Poisoning. *World Journal of Pharmaceutical and Life Sciences*. Vol.4(9):94-99.

Norris, Ruth, A. Karim, Ahmed., S. Jacob, Scherr, and Robert, Richter. 1982. Pills, Pesticides & Profits: The International Trade in Toxic Substances (North River Press, Croton-on-Hudson.

Pham, Hoia, V., Arthur, P.J. Molb, Peter, Oosterveerb, Paul, J. Van, den, Brinkc and Pham, T.M. Huong. 2016. Pesticide use in Vietnamese vegetable production: A 10-year study. *Int. J. Agric. Sustain*., 14(3), 325–338.

Pronczukd, J.G.T.J.S.N.B.J. 2008. Acute pesticide poisoning: a proposed classification tool. Bull. World Health Organization. 86(3), 205–209.

Rajesh, B. 2017. Principles of Forensic Medicine & Toxicology Second edition, Jaypee Brothers Medical Publishers (P) Ltd New Delhi-110002, 2017; 606.

Requirements for Good Agricultural Practices – India GAP. Bureau of Indian Standards, 2010.

Rotterdam Convention.1998, Available from: http://www.pic.int/TheConvention/Overview/tabid/1044/language/en-US/Default.aspx.

Stockholm Convention. 2001. Available from: http://chm.pops.int/TheConvention/Overview/tabid/3351/Default.aspx.

Sudershan, R.V, Pratima R. and Kalpagam P. 2009. Food Safety Research in India: A review. *Asian Journal of Food and Agro-Industry*, 2(3): 412-133.

Uram, C.1990. International regulation of the sale and use of pesticides. *Northwestern J. Int. Law Business*, 10(3), 460–478.

WHO. 2009. International Program on Chemical Safety, Inter-Organization Programme for the Sound Management of Chemicals, World Health Organization, WHO recommended classification of pesticides by hazard and guidelines to classification (World Health Organization, WHO Press, World Health Organization, 20 Avenue Appia, 1211 Geneva 27, Switzerland, 2009).

Chapter - 10

Guidelines of Codex Alimentarius Commission

Vennapusa Chandra Sekhara Reddy, Saraswati Mahato, Hemadri Thammali and C.G. Sawant

Introduction

Codex Alimentarius Commission (CAC) was initially formed by the joint Food and Agriculture Organization and the World Health Organization (FAO/WHO) in 1963. Codex is an inter-governmental organization that operates through a committee structure. The CAC holds meetings annually altering between Rome and Geneva with headquarters at FAO in Rome, Italy. The CAC is mainly intended for the development of globally accepted food safety standards for trading food products across the world. Codex Alimentarius is from Latin, which means "food law" or "legal food code." The CAC has 189 codex members consisting of 188 member countries and one member organization (European Union). The CAC works with international governmental and non-governmental organizations to develop and endorse the standards that make up the international food code.

FAO and WHO fund the Secretariat and administrative support services. The Food and Agriculture Organization provides two-thirds of the funding, while the WHO provides the remaining one-third. Apart from its members, the Commission has 219 Codex Observers, of which 56 are Inter-Governmental Organizations (IGO's), 147 are Non-Governmental Organizations (NGO's), and 16 are United Nations.

Scope

The Codex Alimentarius Standards apply to all fundamental food types, including raw, semi-processed, and processed foods that are intended for human consumption. In general, the term food is referred to as any substance which is processed, semi-processed, or in raw form is manufactured, sold, or intended for human consumption but does not include cosmetics, drugs, and medication products regulate under the Pharmaceutical Profession Act or Food and Drugs Act. In order to maintain the safety and hygiene practices during preparation, cooking, packaging, labeling, and transportation of food items, the Commission had made a set of elements required to follow such as code of standards, code of guidelines, and code of practices applicable to all varieties of food products. In addition to food-specific requirements, the Codex commission includes general food hygiene and quality standards, such as microbiological standards, food additives, pesticides, veterinary drug residues, food labeling and packaging, sampling and analysis methods, and food import-export, certification system, etc. The codex standards, guidelines, and practices are collectively referred to as codex texts. At present, there are 223 codex standards, 78 codex guidelines, and 53 codex codes of practices listed in the Commission. These codex texts apply horizontally to a wide variety of food types and processes. The codex texts are majorly ensured hygiene, labeling of foods, information about food additives, food inspection and certification, information about nutrients for particular dietary use and residual contaminants, etc.

Objectives

» To safeguard customers' health

» To ensure that the food trade is conducted fairly

» To coordinate all efforts related to food safety

» To establish priorities

» To begin the process of preparing standards

» To publish the standards

Functions

» Assures that items that meet codex criteria can be sold worldwide without jeopardizing consumers' health or interests.

» Codex standards ensure that the product is safe around the world.

» Revision of member laws in accordance with internationally recognized scientific and technological norms.

Codex Procedural Manual

The Codex Procedural Manuals are one of the essential Codex documents as it contains:

- » It provides the Commission's Statutes, Rules of Procedure, and other important information.
- » Additional procedural details on the Commission and its subsidiary bodies' operations.

Structural organization

The central structural organization of Codex is composed of:

- » The Commission
- » The Executive committee
- » The Codex secretariat
- » Codex subsidiary bodies include
  - » General subject committees
  - » Commodity committees
  - » FAO/WHO coordinating committees and
  - » Ad hoc intergovernmental task forces

Executive committee and the responsibilities of its members

The Chairperson of the Commission (Mrs. Awilo Ochieng Pernet, Switzerland) and three Vice-Chairpersons of the Committee make up the Executive Committee. Apart from that, it is made up of seven members from each continent, including Africa and Asia, Europe and the Near East, North America, and the southwest Pacific, as well as six regional coordinators from Africa, Asia, Europe, Latin America, and the Caribbean, the Near East, North America, and the southwest Pacific. This group is in charge of overseeing the standard-setting process, preparing the draught strategic plan, examining observer applications, and providing other recommendations about the Commission's overall work. The Executive Committee is chaired by the Chairperson of the Codex Alimentarius Commission, who is also the President of the Codex Alimentarius Commission.

Codex secretariat

In addition to the staffing of FAO and WHO staff, the Secretariat of the Codex is based in the FAO headquarters in Rome. The Codex Alimentarius Commission assists in implementing the Joint FAO/WHO Food Standards Program and reports to the FAO and World Health Organization Director-Generals.

Codex subsidiary bodies

There are four kinds of Codex subsidiary bodies:

- » General Subject Committees, also known as horizontal committees, is responsible for developing codex standards and guidelines for all foods.
- » Commodity Committees, also known as standing committees, are responsible for developing codex standards for specific food commodities.
- » Committees of the FAO and the World Health Organization (WHO), through which regions or groups of countries coordinate food standards activities in their respective regions, including regional standards development.
- » Intergovernmental task forces that are formed on an as-needed basis and have a set time limit to prepare standards and guidelines on specific issues such as antimicrobial resistance

The established subject committees are,

1. Codex Committee on Contaminants in Foods (CCCF)
2. Codex Committee on Food Additives (CCFA)
3. Codex Committee on Food Hygiene (CCFH)
4. Codex Committee on Food Import and Export Inspection and Certification Systems (CCFICS)
5. Codex Committee on Food Labelling (CCFL)
6. Codex Committee on General Principles (CCGP)
7. Codex Committee on Methods of Analysis and Sampling (CCMAS)
8. Codex Committee on Nutrition and Foods for Special Dietary Uses (CCNFSDU)
9. Codex Committee on Pesticide Residues (CCPR)
10. Codex Committee on Residues of Veterinary Drugs in Foods (CCRVDF)

Functions

Codex General Subject Committees have mainly following functions:

- Develop broad concepts and principles for food in general and individual foods or food groups.
- Approval or review of relevant Codex Commodity Standards provisions.
- Develop significant recommendations on consumer health and safety.

The established codex commodity committees are,

1. Codex Committee on Cereals, Pulses, and Legumes (CCCPL)
2. Codex Committee on Fresh Fruits and Vegetables (CCFFV)
3. Codex Committee on Fats and Oils (CCFO)
4. Codex Committee on Processed Fruits and Vegetables (CCPFV)
5. Codex Committee on Sugars (CCS)
6. Codex Committee on Spices and Culinary Herbs (Hosted by India) (CCSCH)
7. Codex Committee on Milk and Milk products (CCMMP)

R/S between Codex subject committees and commodity commodities:

- Furthermore, on any item within their competence, the Codex Commodity Committees may seek advice from general subject committees responsible for matters that affect all foods. During the development of Codex, commodity standards committees and general subject committees should be appropriately referred to each other.
- Unless otherwise imperative, these general provisions are only incorporated by reference in the Codex Commodity Standards.

The established FAO/WHO coordinating committees are,

1. Africa (CCAFRICA)
2. Asia (CCASIA) (*India is the current Regional Coordinator for CCASIA)
3. Europe (CCEURO)
4. Latin America and the Caribbean (CCLAC)
5. Near East (CCNEA)
6. North America and the Southwest Pacific (CCNASWP)

Functions

Main functions of FAO/WHO Coordinating Committees include;

» To encourage mutual exchange of information on planned regulatory measures and food-control issues

» To promote the application of Codex standards in the region and monitor the usage of adopted Codex texts; and

» To conduct general coordination in the production of standards relating to a specific region or set of nations.

Codex Standard Setting Procedure

The preparation of the new codex standard can be made by request from any delegations such as member country or codex observers. The process of new standard-setting follows several reviews by the Commission. Generally, any proposed food standards are initiated in the form of a discussion paper in the body. The request for the establishment of a new standard can be opted by the member country by proposing the need for a standard, the time required in years, and ant its relative priority. The proposal or discussion paper is later arranged into a draft standard by the secretariat. It circulates the same to all members and observers for their critical comments through a web-based system called Codex online commenting system (OCS). The relevant subsidiary body accepts the comments and forwards the text to the Commission as a draft standard. The same draft standard is required to send to the codex committee appointed for food additives and contaminants, hygiene, labeling, and analysis methods for seeking any advice in its area of expertise. Before the final amendments are issued, the draft is further subjected to members and observers for any comments. Once the Commission approves the standard, it becomes a part of Codex Alimentarius and is implemented worldwide. Development of a codex standard requires an average of 4-5 years.

Format of codex standard

A general format of codex standard contains the following column;

» Name of the standard

» Scope

» Description

- Essential composition and Quality factors
- Food additives
- Contaminants
- Hygiene
- Weights and measures
- Labeling
- Methods of analysis and sampling

Codex documentation

Codex documentation is divided into the following main categories:

- Codex Procedural Manual
- ALINORMs
- Committee working papers (CXs)
- Circular Letters (CLs)
- Conference Room Documents (CRDs)
- Information documents (INF)
- Adopted texts

Developed codex standards

1. **Food additives**, this standard deal with externally added substances to food for technical purposes and is not a contaminant or toxicant.
2. **Food hygiene**, this standard regards maintaining the safe condition of food from primary production through to final consumption.
3. **Food contaminants**, this standard, are listed with naturally occurring toxicants that are not intentionally added to food. Mycotoxins are a typical example of contaminants.
4. **Pesticide residues and veterinary drug residues**, this standard contains the maximum residue limits for residue in various food commodities.
5. **Labeling**, this standard furnishes nutritional values, list of ingredients and manufacture and expiry date of food on the top side of covering material.

6. **Methods of sampling and analysis**, a standard which guides for proper sampling of material and test methods to be used for generation of reliable test results for regulatory samples.

7. **Import and export inspection and certification**, this standard system ensures the food and its production system are maintaining as per the specified guidelines to protect the consumers.

8. **The nutritional aspects of foods**, this standard provides information about dietary properties of food, mainly about foods for special dietary uses. This nutritional information is different from ordinary foods.

A Scientific Advisory Committee of Codex Alimentarius Commission

The main principles of developing scientific advice at Codex include

- » Excellence
- » Independence
- » Transparency
- » Universality

The scientific advice is provided by FAO/WHO expert committees and ad hoc expert consultations are as follows;

1. Joint FAO/WHO Expert Committee on Food Additives (JECFA)
2. Joint FAO/WHO Meeting on Pesticide Residues (JMPR)
3. Joint FAO/WHO Expert Meetings on Microbiological Risk Assessment (JEMRA)
4. Joint FAO/WHO Expert meetings on Nutrition (JEMNU)
5. International Atomic Energy Agency (IAEA)

Details about the above meetings as given below

1. **JECFA,** Joint FAO/WHO expert committee on Food additives, was formed in 1955. This committee is intended to consider chemical and toxicological contaminants and veterinary drug residues in foods for human consumption. This commodity identifies the food additives, referring to JECFA for assessment before accepting codex standards to safeguard the foods.

2. **JMPR,** Joint FAO/WHO meetings on Pesticide residues, started in 1963. This committee had the primary objective of establishing maximum residue limits (MRLs) for pesticides and contaminants in specific food commodities to safeguard the foods with residues.
3. **JEMRA,** Joint FAO/WHO meetings on microbiological Risk Assessment started its functions in 2000. The principle objective is to safeguard the food from microbiological hazards through microbial risk assessment. This committee advises the codes of hygiene practices for food safety.
4. **JEMNU,** Joint FAO/WHO expert meetings on Nutrition, was formed in the year 2010. This committee plays a significant role in providing scientific advice on Nutrition and foods for special dietary use to the Codex Alimentarius Commission.
5. The advices are helpful to set the nutrient reference values (NRV).
6. **IAEA,** the International atomic energy Agency serves to provide scientific advice related to radionuclide contamination in foods during the irradiation process.

Codex India- National Codex Contact Point (NCCP)

The National Codex Contact Point (NCCP) for India is headed at Food Safety and Standard Authority of India-Ministry of Health and Family Welfare, FDA Bhawan, New Delhi. The NCCP act as a link system between Codex and the national codex committee (NCCP) in coordinating and promoting the codex activities in India and updating the work to the Codex. FSSAI has built the national codex committee for dealing with the Codex Alimentarius Commission. FSSAI also appoints the shadow committees of the NCC, which are headed by chairpersons (officers in the rank of joint secretary or above from the concerned department). The shadow committee assists the NCC in some of the following functional areas include:

- Codex Alimentarius Commission
- Methods of analysis and sampling
- Food labeling and hygiene
- Food additives and contaminants
- Residues of pesticides and veterinary drugs in foods
- Nutrition and foods for special dietary use (baby foods formula)
- Fish and fishery products

- » Fats and oils
- » Fresh & processed fruits and vegetables
- » Milk and milk products
- » Spices and culinary herbs
- » Food import, export, and certification system

References

http/www.fssai.gov.in

http/www.fao.org

Joint FAO/WHO Codex Alimentarius Commission. 1992. *Codex Alimentarius*. Food and Agriculture Organization.

Kimbrell, E. 2000. What is Codex Alimentarius? *AgBioForum*, 3(4): 97- 202.

Chapter - 11
Concepts of Acceptable Daily Intake (ADI), Maximum Residue Limit (MRL), Pre-Harvest Interval (PHI), and Good Agricultural Practices (GAP)

Saraswati Mahato, Hemadri Thammali and V. Chandrasekhar Reddy

Introduction

The application of pesticides to different crops results in the deposition of residues at the harvested commodity. The amount of residue deposited in the commodity depends on the nature of the crop, type of pesticide, cultural practices, and environmental conditions under which the crop is grown. Since pesticides are toxic, their continuous ingestion by human beings, even in small quantities, leads to accumulation in the body tissues and results in different health hazard problems. Looking into the current population and their food requirements, it is entirely impossible to eradicate pesticides' application to crops. However, pesticides can be regulated by ensuring minimum residues on food, which can be considered safe for human consumption and the environment.

A concept introduced by the Joint FAO/WHO Expert Committee on Food Additives (1955) and Codex Alimentarius Commission (1964) to regulate pesticide residues to safe levels implemented the Joint FAO/WHO Food Standard Programmes aiming at the Maximum Residue Limits (MRL) of pesticides on different crops.

Acceptable Daily Intake (ADI)

The concept of ADI had first been introduced in 1961 by the Council of Europe and later by the Joint FAO/WHO Expert Committee on Food Additives (JECFA), a committee set up by two UN bodies: the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) (Lu and Kacew, 2002).

It is the daily intake of a pesticide that appears to be without appreciable risk to the consumer's health over a lifetime based on all the facts known at that time. "Without appreciable risk" refers to the practical certainty that an injury will not result even after a lifetime of experience. It is expressed in milligrams of the pesticide per kilogram of body weight per day (mg/kg body weight/day) (Lu and Kacew 2002, Mackey and Kotsonis 2002).

Purpose of ADI

The ADI is a realistic approach to determine the safety of food additives and is a means of achieving some uniformity of approach to regulatory control. It helps to ensure the actual human intake of a substance is well below toxic levels.

Determination of ADI

The ADI is determined from the results of long-term feeding studies with laboratory animals. The intake causing no significant toxicological effect in animals when given daily over their life span and ADI are derived by the application of safety factor (usually 10) to the non-observed toxicological effect level (NOAEL) in the most sensitive species studied:

$$ADI = NOAEL/10$$

Non-Observed Adverse Effect Level (NOAEL)

The NOAEL is the highest dose of a substance in experimental animal studies that do not cause any detectable toxic effects. The NOAEL is expressed in milligrams of the substance per kilogram of body weight per day.

Maximum Permissible Intake (MPI)

MPI = Acceptable daily intake × Average body weight

Maximum Residue Limit (MRL)

Maximum residue limit is the maximum concentration for a pesticide residue in or on food when first offered for consumption resulting from the use of pesticides according to good agricultural practices (GAP). The concentration is expressed in milligrams of pesticide residue per kilogram of the commodity or in ppm of fresh weight of the food and is calculated from the (i) food factor (ii) acceptable daily intake and (iii) average weight of the consumer. For example, suppose the total food (TF) consumed by a man per is 2 kg in which the contaminated food (CF) is 0.5 kg, pesticide present in contaminated food (PCF) is 1 ppm. In that case, ADI is 0.1 mg/kg/day, and the bodyweight of a man is 60 kg, then the MRL is calculated as follows:

Food Factor (FF) = CF/TF

= 0.5/2

= 0.25

Total daily intake of pesticide = PCF × FF × TF

= 1 × 0.25 × 2

= 0.5 mg

Average body weight of man = 60 kg

Daily intake of pesticide in mg/kg = 0.5÷60

= 0.008 mg/kg/day

Since the daily intake is less than ADI (0.1 mg/kg/day), the quantity of contaminated food taken daily will not harm at 1 ppm level of pesticide contamination. The MRL is the level up to which this pesticide contamination of 1ppm can be raised in the food so that the daily intake of pesticide (in this case- 0.008 mg/kg/day) does not exceed the ADI. The quantity of pesticide/day /man is calculated as follows:

ADI = 0.1 mg/kg/day

ADI/day/man = 0.1 × 60

= 6 mg

$$\text{Maximum Residue Limit} = \frac{(\text{ADI/day/man})}{\text{CF}}$$

$$= \frac{(6 \times 1000000)}{500000}$$

= 12 ppm

In this case, the pesticide contamination can be raised from 1 ppm to 12 ppm without harming the man. The quantity of contaminated food in the man›s daily diet remains 500 gm.

Since the MRL cannot be fixed based on the experiment conducted on human beings, the information has to be obtained from the results based on test animals.

Hence, ideally 100 fold, a safety factor is incorporated while fixing MRL for each food commodity.

The situation is made more comfortable by the following considerations:

a. The MRL is based on the assumption that a pesticide is used on the whole quantity of food in question, whereas this will rarely be the case.

b. A substantial loss of residue will occur during storage, processing, cooking, thus leading to a much lower level at the time of consumption.

c. The MRL is related to the level of ADI of the pesticide in question, and the value is assessed on the assumption that the residue will be consumed daily over the entire lifetime.

Relationship between MRL and ADI

MRL are proposed only for pesticides for which ADI has been established. Apart from this, MRL and ADI have no direct relationship. They are based on separate evaluations of different kinds of data and describe two other figures, namely,

i. The maximum concentration of pesticide residue that might be expected to result from good agricultural practice and

ii. The level of residue that, if ingested daily, would be without risk to the consumer.

The two figures (MRL and ADI) are not directly related to their origin and meaning; they can be linked between MRL and ADI. MRL provides some indication of the possible or likely exposure concerning a pesticide for comparison with the ADI. The link can be made by converting MRL (expressed as mg/kg) into the daily intake (expressed as mg/kg body weight/day). There are two basic approaches for making this calculation- theoretical daily intake and estimated daily intake.

Fixation of Maximum Residue Limits at the international level

At the international level, the maximum residue limits of pesticides are fixed by FAO/WHO Committee on Pesticides Residues (Handa *et al.*, 1999). The Codex Committee on Pesticides Residues (CCPR) is an inter-governmental body that advises the Codex Alimentarius Commission. The FAO/WHO Alimentarius Commission was established to implement the joint FAO/WHO Food Standards Programme and have 183 (182 member countries and one member organization) members of the commission. The Codex Committee on Food Standards has the responsibility to:

i. Establish maximum limits for pesticide residues in food items or in groups in food.

ii. Establish maximum limits for pesticide residues in certain animal feeding stuffs moving in international trade where this is justified for protecting human health.

iii. Consider methods of sampling and analysis for the determination of pesticide residues in food and feed.

iv. Consider other matters concerning the safety of food and feed containing pesticides residues.

v. Establish maximum limits for environmental and industrial contaminants showing chemical or other similarities to pesticides in specific food items or groups of food.

Fixation of Maximum Residues Limits in India

In India, the maximum residue limits (MRL) are fixed by the Central Codex Committee of Food Standards, a Statutory Committee under the Prevention and Adulteration Act (PFA), with the Plant Protection Adviser to the Government of India as its Chairman. Codex India, the National Codex Contact Point (NCCP) for India, is located at the Directorate General of Health Services, Ministry of Health and Family Welfare (MOH& FW), Government of India. It coordinates and promotes Codex activities in India in association with the National Codex Committee and facilities India's input to the work of Codex through an established consultation process. The responsibility of enforcement of maximum residue limit lies with State governments.

Pre-Harvest Interval (PHI)

Pre-harvest interval is defined as the wait time between a pesticide application and crop harvesting. The PHI is found under the "directions for use" section of the pesticide label. Always read the label to verify PHI instructions. Complying with a PHI is a legal requirement During the PHI, the pesticide may be broken down in the plant or on its surface. Sunlight, rainfall, and temperature affect the degradation of pesticides.

Importance of pre-harvest interval (PHI) in fruits and vegetables

It is crucial to respect pre-harvest intervals so that MRL for a given crop will not exceed. MRL is the maximum pesticide residues expected to remain on a food product when the pesticide is used according to label directions. When the residues were found above MRL on food, it constitutes a violation of the Food and Drug Act and could also pose a risk to the consumer's health. The harvested crop could be destroyed, seized, or forbidden for export and sale in such situations. Use pesticides only for the crops and pests listed on the product's label and make sure to follow the application rates, the number of applications, and PHI stated on the label.

- Following the PHI will reduce your risk of using pesticides on food.
- If your fruit or vegetable is not listed on the label, that means you cannot apply the product to it.
- Wait times for the same fruit or vegetable can differ between products.
- It is illegal to harvest a crop before the PHI. To minimize pesticide residues, the time listed on the label has been tested.
- Environmental Protection Agency sets limits on the residue levels, called tolerances for every pesticide on each crop, and the PHI helps to meet these safety standards.
- For products that can be applied up to the day of harvest, the label may list '0' (zero) days, or there may be no time listed.
- If you sell your produce and do not follow the PHI, there is a risk of pesticide residue on the produce. Residues above legal limits can keep the crop from the sale or export.

Good Agricultural Practices (GAP)

A multiplicity of Good Agricultural Practices (GAP) codes, standards, and regulations has been developed in recent years by the food industry and producer organizations, but also by governments and NGOs, to codify agricultural practices at the farm level for a range of commodities (Waghmode and Jalindar, 2015).

Definition

Good Agricultural Practices are "Practices that address environmental, economic and social sustainability for on-farm processes, and result in safe and quality food and non-food agricultural products" (FAO COAG 2003 GAP paper). These four 'pillars' of GAP (economic viability, environmental sustainability, social acceptability, and food safety and quality) are included in most private and public sector standards, but the scope which they cover varies widely (Waghmode and Jalindar, 2015).

Concept

The concept of Good Agricultural Practices (GAP) has evolved in recent years in the context of a rapidly changing and globalizing food economy and as a result of the concerns and commitments of a wide range of stakeholders on food production and safety, food safety, and quality and the environmental sustainability of agriculture. GAP applies recommendations and available knowledge to address ecological, economic, and social sustainability for on-farm production and post-production processes resulting in safe and healthy food and non-food agricultural products (Waghmode and Jalindar, 2015).

Objectives

1. Ensure the safety and quality of food products in the food chain.
2. Capture new market advantages by modifying the governance of the supply chain.
3. Improving the use of natural resources, health and working conditions for workers, creating new market opportunities for farmers and exporters in developing countries

Key elements of Good Agricultural Practices (GAP)

1. Prevention of problems before they occur
2. Risk assessments
3. Commitment to food safety at all levels
4. Communication throughout the production chain
5. Mandatory employee education program at the operational level
6. Field and equipment sanitation
7. Integrated pest management
8. Oversight and enforcement
9. Verification through independent, third-party audits

Potential benefits and challenges related to Good Agricultural Practices

Potential benefits of GAP

» Appropriate adoption and monitoring of GAP help improve the safety and quality of food and other agricultural products.

- » It may help to reduce the risk of non-compliance with national and international regulations, standards, and guidelines (in particular the Codex Alimentarius Commission, the World Organization for Animal Health (OIE) and the IPPC International Plant Protection Convention on permitted pesticides, maximum levels of contaminants (including pesticides, veterinary drugs, radionuclides, and mycotoxins).
- » Adoption of GAP help promotes sustainable agriculture and contributes to meeting national and international environmental and social development objectives.

Challenges related to GAP

- » In some cases, GAP implementation and especially record-keeping and certification will increase production costs. In this respect, the lack of harmonization between existing GAP-related schemes and the availability of affordable certification systems has often led to increased confusion and certification costs for farmers and exporters.
- » GAP standards can be used to serve the competing interests of specific stakeholders in agri-food supply chains by modifying supplier-buyer relations.
- » There is a high risk that small-scale farmers will not seize export market opportunities unless they are adequately informed, technically prepared, and organized to meet this new challenge, with governments and public agencies playing a facilitating role.
- » Compliance with GAP standards does not always foster all the environmental and social benefits, which are claimed.
- » Awareness-raising is needed of 'win-win' practices that lead to improvements in yield and production efficiencies and the environment and health and safety of workers. One such approach is Integrated Production and Pest Management (IPPM).

Good Agricultural Practices (GAP) for Agriculture

Good Agricultural Practices for Selected Agricultural Components

Soil

- » Physical and chemical properties and functions, organic matter, and soil biological activity are essential for maintaining agricultural production and determining soil fertility and productivity in their complexity.

- Good soil-related practices include the maintenance or improvement of soil organic matter through the use of soil carbon-built by appropriate crop rotations, the application of manure, pasture management, and other land-use practices, reasonable mechanical and/or conservation practices; the maintenance of soil cover to provide a favorable habitat for soil biota, minimizing erosion losses by wind and/or water.

Water

- Agriculture bears a high responsibility for the management of water resources in both quantitative and qualitative terms. Careful management of water resources and efficient use of water for rainfed and pasture production, irrigation, where applicable, and livestock are the GAP criteria.
- Good water-related practices will include those that maximize water infiltration and minimize unproductive surface water efflux from watersheds; manage soil and soil water by proper use or avoid drainage where necessary; improve soil structure and increase soil organic matter content; apply production inputs, including organic, inorganic and synthetic waste or recycled products.

Crop and Fodder Production

- The development of crops and fodder includes the selection of annual and perennial crops, their cultivars and varieties, to satisfy the needs of the local customer and market according to their suitability for the site and their role in the rotation of crops in the management of soil fertility, pests and diseases and their response to the inputs available.
- Effective crop management practices include those that use resistant cultivars and varieties, crop sequences, alliances, and cultural practices that maximize the biological prevention of pests and diseases; establish a regular and quantitative evaluation of the balance of all crops between pests and diseases and beneficial organisms; follow organic control practices where and when applications are applied.

Crop protection

- For good farming, the conservation of crop health is crucial for both yield and product quality. This includes long-term risk management strategies through the use of disease- and pest-resistant crops, crop and pasture rotations, prone crop disease breaks, and the judicious use of agrochemicals to combat weeds, pests, and diseases in compliance with Integrated Pest Management principles.

» Effective crop management practices include those that use resistant cultivars and varieties, crop sequences, alliances, and cultural practices that maximize the biological prevention of pests and diseases; establish a regular and quantitative evaluation of the balance of all crops between pests and diseases and beneficial organisms; follow organic control practices where and when applications are applied.

Animal production

» For welfare and productivity, livestock needs adequate space, food, and water. Stocking rates must be adjusted, and supplements are given for grazing pasture or rangeland livestock as required. To protect animal welfare and/ or to prevent their entrance into the food chain, chemical and biological pollutants in livestock feed are avoided.

» To prevent adverse effects on the ecosystem, climate, and animal health, good practices related to animal production would include those that properly locate livestock units; avoid biological, chemical, and physical pollution of pastures, feed, water, and the atmosphere.

Animal health and welfare

» Effective animal production includes attention to animal health, which is preserved through proper management and accommodation, preventive treatments such as vaccination, and through regular examination, identification and treatment of diseases, and veterinary advice as needed.

» Good animal health and welfare will include those that minimize the risk of infection and disease through good pasture management, healthy feeding, sufficient stocking rates, and good living conditions; maintain clean livestock, buildings, and feeding facilities and provide adequate, clean bedding where livestock is housed; ensure that employees are properly trained in the handling and care of animals.

Harvest and on-farm processing and storage

» The quality of goods also depends on implementing appropriate protocols for the harvesting, storage, and, where applicable, processing of agricultural products. Harvesting must comply with pre-harvest interval regulations for agrochemicals and withholding periods for veterinary medicines.

» Good harvesting and on-farm processing and storage practices will include those harvesting food products after sufficient pre-harvest cycles and withholding periods, ensuring clean and secure handling for the processing of products on-farm.

Energy and waste management

» Energy and waste management are also aspects of sustainable systems of production. Farms need fuel to drive machinery for cultural events, manufacturing, and transportation purposes. The aim is to carry out activities on time, reduce the burden of human labour, increase quality, diversify energy sources and decrease energy usage.

» To ensure efficient use and safe disposal, good practices related to energy and waste management will include those that develop input-output plans for farm energy, nutrients, and agrochemicals; implement energy-saving practices in building design, machinery size, maintenance, and use; examine alternative sources of energy for fossil fuels (wind, solar, biofuels).

Human welfare, health, and safety

» Other components of sustainability include human welfare, health, and safety. To be sustainable, farming has to be economically viable. It is dependent on the social and economic welfare of farmers, farmworkers, and their societies. Health and safety are critical considerations for those engaged in agricultural activities, too.

» Good human welfare, health, and safety practices will include those that guide all agricultural practices to achieve an optimal balance between economic, environmental, and social objectives; provide adequate household income and food security.

References

Handa, S.K., Agnihotri, N.P. and Kulshrestha, G. 1999. Pesticide Residues: Significance, Management, and Analysis. Research Periodicals and Book Publishing House, New Delhi: 13-14.

Lu, F.C. and Kacew, S. 2002. Lu's Basic Toxicology: Fundamentals, Target Organs, and Risk Assessment. Taylor & Francis, Washington DC: 364.

Mackey, M.A., and Kotsonis, F.N. 2002. Nutritional Toxicology. Taylor & Francis, Washington DC:258.

Waghmode and Jalindar. 2015. An attitude of the mango growers towards global gap certification in the Konkan region. Ph.D. thesis. Dr. BSKV, Dapoli, Maharastra.

Chapter - 12

Pesticide Residues and Analytical methods of its detection

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Abstract

Fruits and vegetables play an important role in human nutrition and health; they constitute an essential part of our daily diet. They are a vital source of carbohydrates, vitamins, trace minerals, and antioxidants. Therefore, they can be contaminated by pesticides used for the protection of their culture. The use of pesticides to control pests in fruits and vegetables can lead to pesticide residues. If good agricultural practices (GAP) were used, these residues could be below the maximum residue limit (MRL). The presence of residues with the level exceeding MRLs should be interpreted as a violation of GAP. In many reports, pesticide residues are present in most fruits and vegetables; they are more detected in fruits than in vegetables. The percentage of exceeding MRLs is less than 20 % in most monitoring programs.

Introduction

Pesticides are a subject of debate in today's society. In the past, these products were synonymous with the control of agricultural production, the guarantee of food resources, and the eradication of diseases transmitted by insects. Since the middle of the twentieth century, the excessive and unreasonable use of pesticides has led to widespread contamination of the environment. Since the 1970s, these products and their metabolites have been detected in all environmental compartments, including air, river water, groundwater, and food. The current global trend is to gradually decrease their use by improving agricultural practices and strengthening the legislative measures related to their registration and usage. To this end, the maximum residue limits (MRLs) in fruits and vegetables imposed by international legislation have become lower.

Fruit and vegetables are rich in vitamins and minerals. They also contain antioxidants, such as beta-carotene and vitamin C; they also contain fiber. This can help to control cholesterol levels and keep blood sugar levels steady. Regular monitoring of residue levels in fruits and vegetables is so required to keep these products safe.

Vegetables and fruits, both raw and processed, are vital to enrich human nutrition and health. Indian growth in horticultural crops is from the sustenance level of meeting the local demand to a regional one. It has slowly but steadily and firmly assumed the industrial overtone over the years. In the light of today's health-conscious society, pesticide residue is a crucial issue in fruits and vegetables. The estimated crop loss due to insect pests, pathogens, and weeds are 14, 13, and 13%, respectively (Pimentel 2009). While comparing worldwide consumption scenario, herbicide ranks first, contributing 44%, followed by fungicides/bactericides (27%), insecticides (22%), and miscellaneous (7%) (FICCI 2013) (Fig. 12.1).

In India, pesticide use in agriculture is less than 350 g ha^{-1} as against the world with an average of 500 g ha^{-1}. The United States, though known to be the most health-conscious country, utilizes nearly four times higher pesticides than India, but Americans use pesticides judiciously. Of the 20 effective pesticides used in India, 14 are insecticides. Phorate and methyl parathion take the first two positions, respectively, followed by quinalphos, acephate, triazophos dichlorvos, fenvalerate, dimethoate, chlorpyrifos, phosalone, and carbofuran (Bhushan *et al.*, 2013).

Pesticides are more intensely used on fruits and vegetables worldwide, which the part of fruits/ vegetables i.e., considered as economical or the part of consumption. The presence of pesticide residues poses potential problems instead compared to other crops. Nevertheless, pesticides are often inevitable on these crops since, without these, the loss to fruits and vegetables from pest injury would reach 78% and 54%, respectively (Cai, 2008). Vegetables and fruits consume about 14% of total pesticides in India, while the cropped area is only 3%.

Pesticide Usage in Vegetables

In India, chilli crop recorded maximum pesticide usage, followed by brinjal, cole crops, and okra, and the average pesticide consumption is 0.678 a.i. kg ha^{-1} (Rai, 2014). It is a matter of usage of that non-recommended pesticides were reported on vegetables vegetables (Rai, 2014). All India Network Project (AINP) on Pesticide Residues reported the presence of residues above MRL in capsicum, green chilli, cauliflower, cabbage, brinjal, tomato, okra, bitter gourd, cucumber, green pea, and coriander leaves. The common insecticides are from organophosphates to neonicotinoids (chlorpyrifos, dichlorvos, ethion, cypermethrin, and acetamiprid) on vegetable crops (AINP on

Pesticide Residues, 2015). All India Network Project on Pesticide Residues monitored the residues in vegetables from 2008 to 2012, and a compilation shows that 12.8% of samples were with detectable levels of residues and 2.1% above MRL (Fig. 2 & 3).

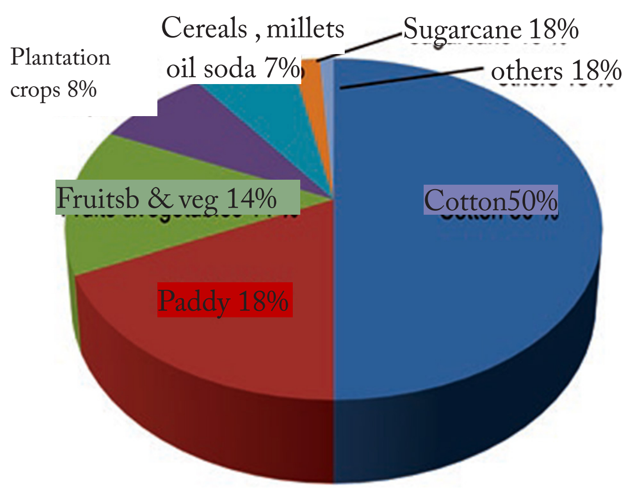


Fig 12.1 Crop-wise pesticide consumption in India. (Source: FICCI, 2013)

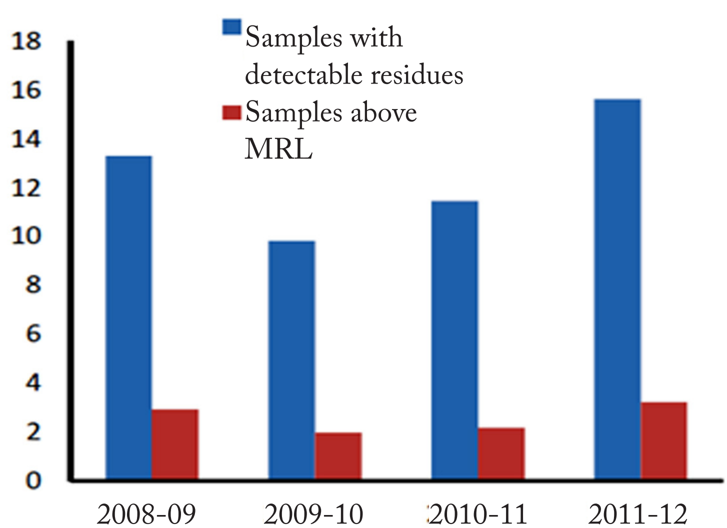


Fig 12.2 Monitoring of pesticide residues on vegetables.
(Source: AINP on Pesticide residues, 2013)

Pesticide Usage in Fruits

Central Insecticide Board and Registration Committee (CIBRC) have recommended many insecticides for all the fruit crops grown in India. AINP on Pesticide Residues reported that out of 2,235 samples of orange, grapes, banana, mango, guava, pomegranate, and apple, pesticide residue in 36 samples (1.6%) was above MRL. Amongst those, grape samples had a high number of above MRL residues with a majority of buprofezin and Chlorpyriphos. Chlorpyriphos is the major insecticide that was found as residue in many fruits (AINP on Pesticide Residues, 2015). AINP on Pesticide Residues monitored the residues on fruits from 2008 to 2012 and showed that 8.36% of samples were with detectable residues and 0.8% above MRL. Unlike the case in vegetables, samples with residues above MRL were reduced from 2008 to 2012, but samples with detectable residues increased (AINP on Pesticide Residues, 2013).

Realizing the importance of Insect Pest Management (IPM), almost all countries advocated and adopted IPM practices for sustainable agricultural growth and development worldwide. Recently, Supreme Court banned endosulfan, which has created a practical problem for farmers to choose better alternatives to endosulfan. Endosulfan was commonly available, cheap, and effective on target pests, thus popular amongst farmers.

Toxicological Risks of Pesticides

The presence of pesticides in the various compartments of the environment results mainly from the intentional application of these products on crops and forests (spreading or spraying) as part of the fight against bio-aggressors or for other uses (domestic, public health, fight against vector-borne diseases, etc.) but also unintentionally following accidents related to manufacturing, transport, and storage. Pesticides in the environment cause different types of pollution that can have adverse effects on living organisms. For humans, apart from occupational exposure, exposure to pesticides is indirect from their environment and due to these, the toxic substances will reside in the natural environment,food, and drinking water.. Multiple routes of exposure to pesticides can be encountered in humans; occupational exposure is mainly for people handling the products. Farmers are a particularly exposed population; in agriculture, the exposure is mainly cutaneous and rarely oral; the absorption of pesticides by the skin is revealed as the most significant route. In several epidemiological studies, there has been a significant association of pesticide use among farmers and the occurrence of certain types of cancer such as cancer of the lips, prostate, stomach, kidneys, brain, but also most cancers of the hematopoietic system (leukemia, multiple myeloma and especially non-Hodgkin's lymphoma), cutaneous melanoma and soft tissue sarcomas.

Problems associated with injudicious use of chemical pesticides

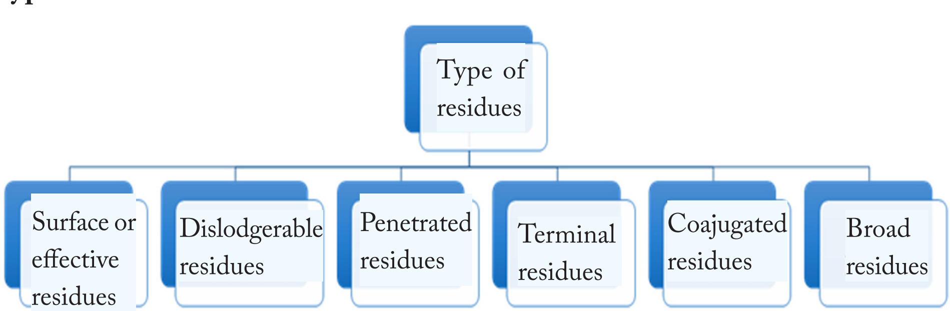
- » Development of insecticide resistance
- » Adverse impact on biodiversity and the environment
- » Adverse impact on health
- » Reduction of beneficial species and outbreak of secondary pest
- » Groundwater contamination
- » The drift of sprays and vapors: During the application, the drifted chemical is going to accumulate in any living bodies leading to bio-magnification, in turn resulting in health hazards
- » Pest resurgence
- » Pesticide residues

Among the problems mentioned above, pesticide residues are the most common, and they cause chronic effects.

Pesticide Residues

According to the Codex Alimentarius, a pesticide residue is any substance (derivative, metabolite, impurity, etc.) present in food, agricultural products, or animal feed due to the use of pesticides. Indeed, after application, phytosanitary products evolve quantitatively and qualitatively over time. The amount of active substance or its transformation products present in the plant at harvest constitutes the residue. Its importance depends first and foremost on the nature of the product used and on some external conditions such as climate, conditions of use, dose, and, in particular, the time to harvest.

Type of residues



1. **Surface or effective residues :** The portion of the pesticides left from the initial deposit.
2. **Dislodgeable residues :** The dislodgeable foliar residue (DFR) is defined as the amount of pesticide residue that can be dislodged from the two-sided foliar surface of a plant during a well-defined procedure. Readily removable may be used as an index for risk assessment to farmworkers. It is used together with worker exposure determinations to calculate transfer coefficients for workers re-entering treated crops.
3. **Penetrated residue *:*** The surface residue becomes penetrated residue by migrating into the sub-strata.
4. **Terminal residue *:*** Breakdown products which are stable and create as many problems as the original compound.
5. **Conjugated residue *:*** The products of secondary metabolism due to the reaction of pesticides or its metabolites with endogenous substrates. There are very few chemicals that enter into biological systems that are not subjected to chemical changes. A few "bio-chemically inert" compounds remain unchanged, although they may be toxicologically active. The type of change that occurs depends primarily upon the structure of the compound, but other factors such as species, route of an entrance, and nutritional balance may also be necessary. There are several types of synthetic reactions common to pesticides.
6. **Bound residue *:*** Chemical substances in soil, plant, or animal tissues originating from pesticide usage that cannot be extracted by the methods commonly used in the analysis. The bound residue is tightly associated with the solid matrix, often forming covalent (or similar) bonds. These residues usually cannot be released from the matrix or can only be released under extreme conditions where the integrity of the substance and/or matrix is likely to be affected. Such residues are often indistinguishable from the natural organic material, e.g., humus in the soil. These residues are not available for either degradation or indigenous organisms and should not be considered in any impact/risk assessment.
7. **Extractable residue :** A residue that is extractable using 'mild' extraction methods. This may include aqueous and cold solvent extraction methods without excessive added energy. Extractable residues are either freely available or only weakly adsorbed to the matrix, are considered bioavailable, and must be regarded as in any impact/risk assessment.
8. **Non-extractable residue :** A residue that is not extractable using 'mild' extraction

methods, but extractable under harsher conditions. These conditions may include solvent extraction using refluxing, microwaves, or accelerated solvent extraction (ASE). These residues are strongly associated with the matrix; however, they may be potentially reversible; but the partitioning is very much in favor of 'binding' to components of the matrix. Therefore, for risk assessment purposes, this matrix-associated fraction is unlikely to be available to indigenous organisms.

Few important terminologies

i. **Maximum Residue Limit (MRL) :** It is the maximum level of pesticide residue that is legally permitted or recognized as acceptable on food, agricultural commodity, or animal feed; it is expressed in milligrams of residues per kilogram of foodstuff. Good agricultural practices for an active substance and a given crop correspond to the practice that leads to a residue concentration below the MRL. It usually reflects:

   » The time before harvest

   » Compliance with the dose per hectare indicated by the manufacturer

   » Compliance with the number of applications per season

An exceedance of the MRL must be interpreted as a non-compliance with an agricultural practice (generally no respect of the pre-harvest period). Codex MRLs are used as a national standard by many countries; however, some countries continue to establish their own MRLs or tolerances and impose zero tolerance to residues of pesticides on imported crops which do not have nationally/regionally agreed-upon MRLs, like in India- the MRLs given by FSSAI are considered.

ii. **Acceptable Daily Intake (ADI) :** It is the amount of a chemical present in the diet, which can be ingested daily by the consumer throughout his life without adverse effects on his health. It is calculated on the basis of toxicological studies from NOAEL (no-observed-adverse-effect level) observed in animals, divided by a safety factor taking into account intra-individual variability, interspecies variability, uncertainty associated with experimental protocols, and, if necessary, the nature of the effects of the substance. ADIs are set by scientific assessment organizations at the international (JMPR: joint meeting of pesticide residues FAO/WHO Expert Committee), community (EFSA: European Food Safety Authority), or even national level. The ADI is used for the evaluation of food additives, pesticide residues, and veterinary anti-parasitics. It is expressed in milligrams of substance per kilogram of body weight per day (mg/kg body weight/ day).

iii. **Acute Reference Dose (ARfD) :** It refers to the maximum amount of active substance (expressed as mg of active substance per kg of body weight) that can be ingested by the consumer for a day or less, in food or drinking water, with no adverse health effects. It is calculated from a no-observed-adverse-effect level (NOAEL) and a safety factor. The NOAEL chosen for the calculation comes from the most appropriate study on a sensitive and representative animal species. The safety factor takes into account intra and interspecies variability and the nature of the effects of the substance.

Pesticides fate after application to fruits and vegetables

Fate refers to the pattern of distribution of pesticide, its derivatives or metabolites in an organism, system, compartment or (sub) population of concern as a result of transport, partitioning, transformation or degradation (OECD, 2003). After pesticides are applied to the crops, they may interact with the plant surfaces, be exposed to the environmental factors such as wind and sun and may be washed of during rainfall. The pesticide may be absorbed by the plant surface (waxy cuticle and root surfaces) and enter the plant transport system (systemic) or stay on the surface of the plant (contact). While still on the surface of the crop, the pesticide can undergo volatilization, photolysis, chemical and microbial degradation. Volatilization of the pesticide usually occurs immediately after application in the field. The process depends on the vapour pressure of the pesticide. Pesticides with high vapour pressure tend to volatilize rapidly into the air while those with low vapour pressure remain longer on the surface. Volatilization rate also depends on the environmental factors such as wind speed and temperature. The faster the wind speed and higher the temperature, the more the pesticide will evaporate. Photolysis occurs when molecules absorb energy from the sunlight resulting in pesticide degradation. The indirect reaction can also be caused by some other chemicals being broken by the sunlight and their products reacting with pesticides in turn. Some pesticides may be degraded by microbial metabolism. Micro-organisms can use pesticides as nutrients thereby breaking them into carbon dioxide and other components (Holland and Sinclair, 2004). Because of the difference between naturally occurring organic chemicals and pesticide structures, they cannot be assimilated by the microbes but they may be altered at reactive sites. The products formed may be less or more toxic than the parent chemical.

Analytical Methods Applied to the Research of Pesticide Residues

Pesticide residues in foods have received a great deal of attention as an important element in food safety, and as a result, national and international laws have become stricter in respecting MRLs. Monitoring residue levels in food require reliable methods of analysis. Nevertheless, pesticides are generally present at very low concentrations in the environment and in food. Their number is high, and they are of different physicochemical natures. Research and quantification of their residues are a permanent challenge and require the implementation of highly sensitive and reliable multi-residue analysis methods. Several methods of analysis exist, and their choice depends on the nature of the pesticides studied and the targeted matrices.

Steps in analysing pesticide residue

Different steps are necessary to determine the pesticide residues from fruits and vegetables, starting with the scientific Sampling; extraction of the residues in proper solvents; clean-up of the extracts and estimation using chromatography.

1. Pre-treatment and extraction methods

A wide range of pre-treatment and extraction techniques are being used for the determination of pesticide residues in fruits and vegetables. There are no generally accepted, standard methods for the extraction of pesticides in laboratories. Moreover, the extraction procedure follows a common pathway involving the release of desired analyte from the matrices, followed by a clean-up process which refers to a step or series of steps in the analytical procedure in which the bulk of the potentially interfering co-extracts are removed by physical or chemical methods (solid-liquid or liquid-liquid extraction).

The extraction procedure initially deals with the preparation of sub-samples. The starting material consists of 0.5–2 kg samples, which are homogenized by a mixer after cleaning. The homogenized sub-samples ranging from 0.5 to 100 g are taken for further extraction. As per the literature, some of the most commonly used solvents for analysing pesticide residue in fruits and vegetables are acetonitrile, ethyl acetate, dichloromethane, methanol and toluene. In certain cases, the mixtures of solvents are used to improve the recovery of the methods. In addition, the use of agents such as sodium hydroxide and acetic acid are also used to neutralize the matrices and in turn to produce better recovery (Andrade *et al.*, 2015).

Initially, the application of liquid – liquid extraction (LLE) and solid phase extraction (SPE) were been used in the extraction process due to their simplicity. However, over the past decade, the use of (QuEChERS) - 'Quick Easy Cheap Effective Rugged and Safe' method increased tremendously due to its micro scale extraction process (Lehotay *et al.*, 2010). Extraction of organic compounds from different matrices (e.g., food, biological, and environmental) is a time-consuming process, but the QuEChERS method reduces the analysis time, minimize the number of analysis steps with the use of fewer reagents in smaller amounts and in turn provides high recovery.

In few of the published methods, comparison of extraction methods have been carried out where, Afify *et al*., (2012) have reported a method in comparison with the QuEChERS, ethyl acetate and Luke extraction method (Luke *et al*., 1975). The research findings concluded that Luke method had significant effect only on the recovery of non-polar and medium polar compounds while, ethyl acetate produced significant recovery for polar compounds alone. But QuEChERS method produced good recovery for none, medium and polar compounds over the recovery range of 60–70%. However, compared to the other methods, Luke method was found to have minimal cleaning procedure. Nevertheless, the extraction procedure has been evolving over the past few years, in simplifying the sample preparation process, reducing the analysis time and usage of toxic solvents.

Liquid-liquid extraction (LLE)

LLE also called solvent extraction and partitioning, which entails the separation of compounds, primarily based on their relative solubility in exceptional immiscible liquids. LLE is one of the oldest and well established methods for the extraction of pesticides, which is reliable, adaptable and compatible with the majority of the instruments. Different extraction solvents are used for LLE such as hexane, acetonitrile and ethyl acetate which is one of the most commonly used medium polarity solvents for the extraction of pesticides from food matrices (Cho *et al*., 2013).

LLE method was conducted by Grimalt *et al*. (2010) for simultaneous detection of eleven pesticides of different classes. The extraction was carried out with methanol-water and filtered through nylon syringe filters before analysis. Despite, the LLE methods are well recognized, the major drawbacks includes consuming large volume of toxic solvents, requires long analysis time, difficult to automate and less effective against polar compounds. In addition, LLE method are also not specific to any particular analyte and extracts all molecules from the matrix and causes high matrix interferences.

Solid-phase extraction (SPE)

SPE is the most commonly used method due to its simplicity, rapidity and its ability to treat a large volume of samples with high recovery. A wide range of SPE cartridges is used for the pre-treatment and determination of pesticide residues in fruits and vegetables. Few methods have been reported by florisil column, C18 columns and Envicarb cartridges to determine pesticide residues. Liu *et al*., (2010) have developed an extraction method by SPE HLB cartridge and Extrelut NT 20 column for analyzing neonicotinoid pesticides. Similarly, Balinova *et al*., (2007) have developed an extraction method using sorbents of different retention mechanism (SAX PAX and GCB sorbent).

A majority of residual estimation is being carried out by typical sorbents such as a primary secondary amine (PSA) and graphitized carbon black (GCB). In some cases, sorbents (PSA-GCB-C18) are used together in the clean-up process to improve the sensitivity of the methods. In addition to the above sorbents, multi-walled carbon nanotubes (MWCNTs) are employed in the extraction of pesticides due to their effectiveness. In addition to the sorbents, organic solvents have been used in individual or mixture for the extraction and elution of the pesticide residues and it becomes necessary to acquire an appropriate solvent for its intended purpose.

The choice of solvents used depends upon the molecular characteristics (ionic and non-ionic) of the pesticide to be analysed. Solvents such as acetonitrile, methanol, ethyl acetate, dichloromethane, acetone, acetic acid, hexane, toluene, petroleum ether, cyclohexane, diethyl ether are usually used. SPE method is reported to be the fastest and efficient method for pesticide analysis. Though, the SPE methods provide better separation and recovery from complex matrices, due to its perceiving difficulty to master its usage it becomes a tedious process. Furthermore, this method causes clogging of cartridges by the samples suspended matter and has the possibility of low recovery by interaction of sorbents towards the analytes.

Solid phase micro-extraction (SPME)

Solid phase micro-extraction is a simple, sample preparation method introduced by Arthur and Pawliszyn (1990) during 90's which had some outstanding features like solvent-free, fast, portable and easy to use. SPME is based on the partitioning of analytes between a phase immobilized on SPME fibre and the matrix. Recently, Zhang *et al.*, (2017) have applied SPME method combined with a gas chromatography coupled with micro electron capturing detector (GC-μECD) system to determine eight pyrethroids (bifenthrin, fenpropathrin, cyhalothrin, permethrin, cyfluthrin, flucythrinate, fenvalerate and deltamethrin), in which a novel ZIF-90-NPC coated SPME was fabricated via physical adhesion approach. The method LODs ranged between 0.1 - 0.5 ng g^{-1} with a wide linearity range of 0.3–50 ng g^{-1}. Another study by Abdulra'uf and Tan (2015) reported a method using headspace-solid phase microextraction in fruits and vegetables and analyzed by gas chromatography-mass spectrometry (GC–MS). Similarly, Kin and Huat (2010) have determined pesticide residues in strawberry and cucumber sample using headspace solid-phase microextraction method using GC-ECD.

As compared to the commercial SPME fibres such as polyacrylate (PA) and polydimethylsiloxane (PDMS), this study showed better extraction efficiency. The major drawback of this method is its difficulty in the sample carryover, fragility of the fibre and its limited lifetime in the extraction process. Moreover, effectiveness of the extraction process is low due to the low PDMS fibre coating and the interaction in the sorption process between the analytes in the fiber and the analytes in the sample matrix.

Matrix solid-phase dispersion (MSPD)

This method was firstly described by Barker *et al.*, (1989) which is used to extract solid and semi-solid samples. In MSPD, extraction and clean-up are integrated into a single step, thus making the procedure easy, fast with less sample loss and solvent consumption. However, the MSPD method requires a number of variable optimization such as sample amount, dispersant material (type and amount) and elusion composition.

A comparative study between modified QuEChERS and MSPD method was performed by Gilbert-Lopez *et al.*, (2010) for about 105 pesticides. The SPME extraction was based on liquid partitioning with acetonitrile saturated with petroleum ether followed by MSPD using amino propyl as sorbent material and florisil cartridge for final clean-up. For QuEChERS method, liquid-liquid partitioning with acetonitrile followed by dispersive solid phase extraction and further clean-up using GCB, PSA and C18 sorbent were carried out with final detection using fast liquid chromatography-electrospray time-of-flight mass spectrometry (LC-TOF/MS). The research findings concluded that the optimized QuEChERS method showed better extraction efficiency than MSPD. The LODs were obtained over the range of 0.2–10 $\mu g\ kg^{-1}$ with percentage recovery of 70 to 130%.

Quick, easy, cheap, effective, rugged, and safe method (QuEChERS)

In 2003, a new strategy was introduced which was based on acetonitrile extraction followed by a clean-up using dispersive-solid phase extraction (d-SPE) (Anastassiades *et al.*, 2003). They termed this sample treatment procedure as QuEChERS. This method became popular because of its microscale extraction procedure which is simpler, consumes less time and organic solvent than all the previous methods. The commonly used procedure involved the use of acetonitrile in extraction process due to its high recovery. Though, acetonitrile is miscible in water, it can be separated by salt out effect before the final clean up by d-SPE tubes and MWCNTs (Moreno *et al.*, 2008). In some cases, ethyl acetate is used as an extraction solvent, though the major drawback of ethyl acetate solvent was its ability to lose basic pesticides in an acidic matrix. Hence, to overcome this problem sodium bicarbonate were suggested (Aysal *et al.*, 2007) to improve the recovery of the analytes.

A study conducted by Carneiro *et al.* (2013) developed the QuEChERS method with no clean-up process. The proposed method successfully detected 128 analytes with detection and quantification limit of 5 μg kg^{-1} and 10 μg kg^{-1}, respectively. The method proved to be simple and offered an excellent recovery (70–120%) with RSD value <20%. The authors also concluded that the matrix effect was within the limits during the analysis.

Further, fewer literature described that the change in pH may influence the recovery of certain pesticides in QuEChERS technique. The use of acetate buffer also yields a high recovery from pesticides which are pH dependent. Nowadays, the modified QuEChERS method has been used with a change in solvent conditions such as methanol and ethyl acetate which is more suitable in the detection in Gas and Liquid Chromatography.

Over the past few years, QuEChERS approach has surpassed through a drastic change, which has been superior to its traditional techniques and it is also been used notably due to its advantages of being flexible and effective in the extraction of a wide scope of analytes with a low volume of solvent. A comparative study was also conducted between QuEChERS, MSPD and dispersive ethyl acetate for the analysis of 98 pesticides in globe artichoke. The findings concluded that the use of QuEChERS method was efficient with the addition of calcium chloride in the clean-up step for its ability to dehydrate the sample and to form insoluble calcium salts with catecholic hydroxyls. In addition, the detection of the method was carried out by GC–MS and LC-MS/MS techniques. The respective ranges of LODs were from 0.005 - 0.025 mg kg^{-1} and 0.003–0.015 mg kg^{-1} for GC–MS and LC-MS/MS methods, respectively with 70–120% recovery for both detection techniques.

Other extraction methods

Although QuEChERS extraction methods are the most frequently applied techniques in extraction and clean-up in food samples, other methods are also applied for the extraction of pesticide residues as alternatives in laboratories.

» Gel permeation chromatography (GPC) also known as size exclusion chromatography that separates analytes on the basis of size are used in the analysis of pesticides. However, all these traditional methods had some drawbacks such as long operation hours which consist of multi-step and high cost due to the increase in the consumption of organic solvents which makes them hard to use in large-scale operations.

» Dispersive liquid-liquid microextraction (DLLME) is an another form of micro-extraction method used for the detection of pesticides. Shamsipur *et al.* (2016) have reported a method which involves the use of DLLME method coupled with SPE for the determination of pesticides in fruit juice, water, milk and honey samples. The detection limit ranged from 0.5 to 1.0 ng kg^{-1}.

» Recently, another form of microextraction method was reported in the pesticide analysis using liquid–liquid microextraction (LLME) (Torbati *et al.*, 2018).

» In addition, a new extraction method involving the use of liquid-solid extraction coupled with magnetic solid phase extraction based on Pst/MNPs has also been reported for the detection of pyrethroid residue by Yu and Yang (2017), which is unique compared to other methods. The study results indicated that the use of magnetic core improved the extraction of target analytes drastically with high efficiency utilizing environmental friendly solvents.

Instrumental Techniques for Detection

Due to the presence of matrix interference, it becomes difficult to develop a method for pesticides in real samples. In the recent years, the most used strategies for detection and quantification of pesticides in fruits and vegetables are Gas and Liquid chromatography due to their sensitivity, separation and identification abilities. Apart from these, other methods such as enzyme-linked immunosorbent assay (ELISA) and capillary electrophoresis (CE) (Chen & Fung, 2010) have also been used in the determination of pesticide residues in real samples. Table 1 summarizes the detection techniques for the estimation of pesticide residues in fruits and vegetables.

Gas chromatography (GC)

Most of the published studies state that the detection of pesticides has been carried out by GC coupled with various detectors. Due to their sensitivity, detectors such as electron capturing detector (ECD), flame photometric detector (FPD), nitrogen phosphorus detector (NPD) and mass selective detector (MSD) are used. In addition, mass detection methods are also employed to improve method sensitivity, which are equipped with analyzers such as ion trap (IT), Quadrupole, triple quadrupole (QqQ), time of flight mass analyzer (TOF).Further, to minimize the matrix interference selective ion monitoring (SIM) or multiple reaction monitoring (MRM) are used, were the analyte mass to charge ratio (m/z) are concentrated to achieve a lower limit of detection and quantification with less interference.

Table 1: Multi-class pesticide residue detection methods

Residue detection method	Detector	Abbreviation
High performance liquid chromatography (HPLC)	UV detector	HPLC-UV
	Photo diode array	HPLC-PDA
Gas chromatography (GC)	Gas chromatography - tandem mass spectrometry (Triple quadrapole)	GC-MS-MS (QqQ)
	Electron capture detector/ nitrogen phosphorous detector	GC-ECD/ NPD
	Time-of-flight mass spectrometry	GC-TOF-MS
Liquid chromatography (LC)	Liquid chromatography with tandem mass spectrometry	LC-MS-MS
Ultra-high performance liquid chromatography (UPLC)	Ultra-high performance liquid chromatography with quadrupole time-of-flight mass spectrometry	UPLC-Q-TOF-MS
Rapid resolution liquid chromatography (RRLC)	Rapid resolution liquid chromatography tandem mass spectrometry	RRLC-MS/ MS
Enzyme-linked immunosorbent assay	-	ELISA
Capillary electrophoresis	Capillary electrophoresis–mass spectrometry	CE-MS

Huškova, Matisova, Hrouzkova, and Švorc (2009) have reported a method for the analysis of pesticide residues by the application of fast gas chromatography coupled with negative chemical ionization mass spectrometry. Ninety per cent of the GC chromatographic separation is carried out with fused silica 30 mm × 0.2 mm i.d., 0.25 μm using helium or nitrogen as a carrier gas. However, over the decade, the use of GC methods has decreased due to the increased use of polar pesticides (less persistence and high toxicity) which are found inappropriate for the GC detection methods due to their volatility and poor thermal stability.

Liquid chromatography (LC) (included HPLC, UPLC)

A wide range of liquid chromatography based techniques have been stated in the analysis of pesticide residues, most of them are coupled with ultraviolet (UV), photodiode array (PDA), diode array detector (DAD) and mass (MS) detectors. The octadecyl (C18) is the most frequently used stationary phase for the chromatographic separation and to decrease the run time, gradient mode has been employed for multi-residue analysis.

Wang *et al*. (2012) have reported a multi-residue method for the determination of seven neonicotinoid insecticides by high-performance liquid chromatography (HPLC) with the use of diode-array detector (DAD) and the separation was achieved by agilent TC-C18 column. Similarly, Al-Rahman, Almaz, and Osama (2012) have developed a method to determine the degradation rate of acaricide fenpyroximate in apple, citrus and grape by HPLC-DAD analysis. Apart from the above methods, Wang, Tang, Qiao and Xu (2014) have reported a method where the use of molecular imprinted solid-phase extraction was done for the determination of trichlorfon, monocrotophos by HPLC.

Although liquid chromatography coupled with UV, PDA and DAD systems are commonly used, it becomes difficult to provide structural information for the identification of residual content of pesticides in fruits and vegetables. Hence, the mass detection technique have been used to overcome these structural interventions and also to provide structural information for molecular masses and fragmentation pattern using tandem mass spectrometry (MS/MS). A number of studies have been carried out by liquid chromatography coupled with mass detection utilizing different reverse phase columns (C-8, C-12 and C-18), organic phases (acetonitrile and methanol) and buffers (formic acid, ammonium formate, acetic acid, ammonium acetate). In some cases, solvent mixtures are also employed (water-acetonitrile and water-methanol) in gradient mode with flow rate ranging from 0.2 to 1.0 mL min^{-1} (Christia, Bizani, Christophoridis, & Fytianos, 2015; Jallow, Awadh, Albaho, Devi, & Ahmad, 2017).

In MS detection, ionization source such as electrospray ionization (ESI) are commonly used (Dzuman, Zachariasova, Veprikova, Godula, & Hajslova, 2015) due to their ability to ionize both polar and non-polar analytes. In addition, mass analyzer such as triple quadrupole (QqQ) (Rong *et al*., 2017) and Q-Trap (Crnogorac, Schmauder, & Schwack, 2008) are used for qualitative and quantitative analysis.

In reference to the use of LC-MS and MS/MS, a new method has been reported in the past few years with the use of ultra-performance liquid chromatography (UPLC) due to its chromatographic efficiency and sensitivity to analyze pesticides in fruits and vegetables. Sivaperumal, Anand, and Riddhi (2015) have reported a method for the determination of pesticide residues in fruits and vegetables with ESI and TOF detection.

Other detection methods

Techniques such as Capillary electrophoresis (CE) and Enzyme-linked immunosorbent assay (ELISA) have also been reported as fast and low-cost separation and detection methods in pesticide analysis. ELISA determines pesticides based on the principle on antigen-antibody interaction which is capable of providing high sensitivity and selectivity to a certain type of pesticides. The major drawback of this method is the antibody un-stability and un-sufficient blocking of immobilized antigen which causes false results.

Navarro *et al*. (2013) have used duplex ELISA to detect the OPs (chlorpyrifos and fenthion) residue in natural and commercial tangerine juice samples. The proposed method was conducted by insertion of two separate ELISAs for the respective OPs into one ELISA test. The method achieved a detection limit of 0.20 to 0.04 μg/L (chlorpyrifos) and 0.50 to 0.06 μg/L (fenthion). The recoveries obtained were over the range of 95% to 106%.

CE is a valuable technique which requires less volume of the reagent and sample by which high separation efficiency is obtained in less time. Recently, Li *et al*. (2017) have developed a method using capillary electrophoresis coupled with a biomimetic immunoassay (BICE) to determine the residue of trichlorfon in the vegetable matrix. The LODs ranged from 0.16 to 0.13 μg L^{-1} with recovery between 78.8 and 103 % for trichlorfon in kidney bean and cucumber samples. The main advantage of this method is the specificity of BI and high separation efficiency of CE, which makes this method more effective compared to other methods. Daniel *et al*. (2015) have reported a CE method coupled with tandem mass spectroscopy for the determination of halosulfuron-methyl residue in tomato and sugarcane juice. The developed method achieved a detection limit of 2 ppm. The results obtained indicated that the MS detection system is the most preferable detection system (high sensitivity), despite the potential disadvantage of being costly.

Comparison of conventional extraction and detection approaches

Various extraction and clean-up procedures such as LLE, SPE, GPC, SPME and MSPD have been developed and employed for the extraction and clean-up of various contaminants in the matrix to produce high sensitive methods through reducing the matrix interferences. Although most of the methods produce good recovery, but they do have some drawbacks such as long equilibrium time, possible carry over and matrix effect. Hence, the use of the QuEChERS method has been explored most intensively for the multi-residue analysis due to its significant extraction efficiency.

This technique is found to be simple, inexpensive and also compatible with the instruments such as Gas and Liquid chromatography. In addition to the conventional method, recent advances in QuEChERS method have been found to increase its efficiency such as the clean-up procedure uses multi-walled carbon nanotubes. Thus, the conventional method uses PSA material for its clean-up, which has the potential to absorb some acidic analytes and to degrade base-sensitive compounds. In some cases, recoveries were being affected due to the independence of the matrix and to solve this problem, a new method was developed which involves the use of buffers such as 1% acetic acid called as buffered QuEChERS method.

Apart from the extraction process, detection of pesticides at lower limits plays a major part in the pesticide residue analysis. Initially, methods based on LC have been used rarely with detectors namely UV, DAD and fluorescence due to its low sensitivity and selectivity. After the introduction of MS, there has been an increase in the usage of the LC systems because of its sensitivity. ESI was found to be the powerful analytical tool for the determination of pesticide residues in fruits and vegetables. From the literature it was observed that the usage of detection methods based on UHPLC system coupled with MS/MS (QqQ) has increased due to its higher sensitivity and selectivity in the detection of pesticide residues in fruits and vegetables and the identification and confirmation of the target and non-target analytes was done in a short time.

Unlikely to LC detection, GC detection was restricted for quantification of compounds which were volatile and thermally stable. Unfortunately, majority of the compounds were non-volatile and increased the use of LC methods for the detection of pesticides.

Measures to Reduce Pesticides Residues

The disappearance/degradation of pesticide residue takes place by two ways i.e. dissipation (in which the disappearance of the residue is fast) and persistence (in which there is a slow decrease in the amount of residue).

The location of pesticides in different parts of food varies with the nature of molecule, type of food commodity exposed to pesticides and environmental conditions (Temperature, RH and rainfall etc.). The amount of pesticide remaining after a half-life (RL_{50}) depends upon the amount of pesticide originally applied for pest control (NPIC, 2011). Pesticide can be degraded by photolysis, hydrolysis, oxidation and reduction, metabolism (plants, animals or microbes), temperature and other environmental factors and pH of soil, water and pesticide (Helfrich, 2009). The retention of pesticides depends on the physical and chemical properties of the pesticide molecules as well as food or commodity under exposure.

Table 2: Difference between gas chromatography and liquid chromatography

Gas chromatography	**Liquid chromatography**
Stationary phase: Solid/liquid	Stationary phase: Solid/liquid
Mobile phase: Gas	Mobile phase: Liquid
Mobile phase does not take part in separation	Mobile phase take active part in separation
Seperation of volatile organic/inorganic compound only	Volatile as well as non-volatile compounds can be separated
Works at comparatively low pressure	Works at high pressure
Works on both packed as well as capillary columns	Only packed columns for analysis
Fast and better efficiency obtained	Slow and poor efficiency
Selective columns for applications	Very few selective columns available
Range of selective detectors available for detection	Few selective detectors available
Environment friendly technique	Solvents eluted after separation needs to be disposed off properly hence non-environment friendly technique
Detectors such as FID, ECD, TCD and NPD are used	Photo Diode Array (PDA), DAD, fluorescence detector are used

In fruits and vegetables, most of the pesticide residues are retained on peel surface (Awasthi, 1993). This is the reason that majority of the residues are removed by washing, peeling or treatment with chemical solutions like vinegar, turmeric, sodium bicarbonate, common salt or alcohol (Gupta, 2006).

The level of pesticide residue is influenced or affected by washing, preparatory steps, cooking or heating, processing during product manufacturing and post-harvest handling and finally storage condition. The extent of pesticide reduction varies with nature of pesticide molecule, point of location in commodity (outer surface, translocate inside the commodity etc.), type of commodity, processing steps and product prepared. The washing of raw materials (either with tap water or salt or dilute solutions) is the simplest way to reduce the pesticide residue in the final product. The more effective and convenient alternative could be washing with chlorine water or with dilute solutions of other chemicals depending upon type of food commodity. Special precautions should be taken to dislodge the residues from raw materials to be used for preparation of concentrated and dehydrated products. Judicious and systematic approach should be followed to adopt pre-harvest practices and post-harvest treatments to minimize the residue levels in finished products.

Decontamination of pesticide residues from food commodities remains the main concern for consumers particularly when these are consumed raw. Several decontamination procedures are being evaluated for effective removal of pesticide residues from various vegetable such as okra, chilli, cabbage, cauliflower, tomato and brinjal. Many of the decontamination techniques bring down the concentration of pesticides below MRL. However, the diminution effect depends upon the initial concentration at the time of harvest, substrate/food and type of pesticide.

The washing of food commodities with water or soaking in solutions of salt and some chemicals e.g. chlorine, chlorine dioxide, hydrogen peroxide, ozone, acetic acid, hydroxy per acetic acid, iprodione and detergents are reported to be highly effective in reducing the level of pesticides. Preparatory steps like peeling, trimming etc. remove the residues from outer portions. Various thermal processing treatments like pasteurization, blanching, boiling, cooking, steaming, canning, scrambling etc. have also been found valuable in degradation of various pesticides depending upon the type of pesticide and length of treatment.

Many other techniques like refining, fermentation and curing have been reported to affect the pesticide level in foods to varied extent. Milling, baking, wine making, malting and brewing resulted in lowering of pesticide residue level in the end products. Post-harvest treatments and cold storage have also been found effective.

Removal of pesticides in fruits and vegetables

Several techniques are available for decontaminating the fruits and vegetables from pesticide residues. Easiest and common method, convenient to be done in small as well as large scale, includes washing in cold, hot or hard water. Removing the outer layer of fruits, cooking, drying and canning are also effective. The effect of washing decreased with increased aging of residues. Culinary processes can also be done by chemical treatments. The brinjal fruits were dipped in water and in 2% aqueous solutions of sodium chloride, hydrochloric acid, acetic acid, sodium hydroxide, potassium permanganate and teepol (detergent) for 10 min. Dip treatment of fruits in detergent solution removed 50–60% of surface residues against 40–45% removed by hydrolytic degradation with alkali solution. The acids and other chemicals could remove only 30–35% residues (Awasthi, 1986). A sensitive and modern screening method was successfully developed and applied for targeted and non-targeted analysis of agrochemical residues in fruits, vegetables and their processed products. A generic method of sample preparation was developed for simultaneous analysis of various classes of contaminants at 10 ppb and lower levels. A precise and sensitive residue analysis method was validated for the estimation of dithiocarbamate fungicides in fruit and vegetable matrices. Dissipation studies on imidacloprid, carbendazim, kresoxim methyl, flubendiamide, buprofezin and hexaconazole were carried out in okra, and their pre-harvest intervals (PHI) were estimated (Directorate of Agriculture, Research and Education (DARE, 2015).

Good agricultural practices (GAPs) to minimize pesticide residue

1. Encourage integrated pest management (IPM) strategies.
2. Justify the treatment of planting material.
3. Use only registered pesticides and avoid sub-standard ones.
4. Use minimum chemical pesticides.
5. Avoid indiscriminate use of chemical pesticides.
6. Apply pesticides only when pest populations are large enough to cause economic losses.
7. Apply pesticides according to label directions in terms of dosage, crop, canopy, time of application, waiting period etc.
8. Use right kind of spray depending upon the pest and crop canopy.
9. Dispose the pesticide container and polythene safely by burying.
10. Do not use damaged containers.
11. Avoid wrong disposal of left over pesticides.
12. Maintain records of all pesticide applications properly.
13. Persons applying pesticides must read the instructions carefully and comply with it.
14. Use protective clothing while applying pesticides.
15. Avoid repeating the same group of chemicals again and again; hence different chemicals may be rotated so that the insect pests do not develop resistance.

Conclusion

There has been a tremendous improvement in the pesticide residue analysis in fruits and vegetables due to the increase in the importance of food safety. Various pre-treatment, extraction and detection techniques are being developed which has reduced the time, sample size and interference during analysis. Though, the choice of extraction and detection system remains the same which consists of the traditional extraction and detection system coupled with mass for quantification. However, these methods are time-consuming and expensive. Recently, the use of advanced methods such as bio-sensor, molecular imprinted polymer and nanotechnology based method are utilized as better alternative for the detection of pesticides. However, in the near future, limitations in these advanced methods needs to be resolved, to develop a favourable cost-effective and eco-friendly method which could detect a large number of pesticide residues in a single run at lower limits.

References

Abdulrauf L. B., Tan G. H., 2015. Chemometric approach to the optimization of HS-SPME/GC–MS for the determination of multiclass pesticide residues in fruits and vegetables. *Food Chemistry*, 177, 267-273.

Afify A. E. M. M., Attullah E. R., El-Gammal H. A., 2012. A modified multi-residue method for analysis of 150 pesticide residues in green beans using liquid chromatography-tandem mass spectrometry. *Advances in Food Sciences*, 34(1), 24-35.

Anastassiades M., Lehotay S. J., Stajnbaher D., Schenck F. J., 2003. Fast and easymultiresidue method employing acetonitrile extraction/partitioning and "dispersive solid-phase extraction" for the determination of pesticide residues in produce. *Journal of AOAC International*, 86(2), 412-431.

Andrade G., Monteiro S., Francisco J., Figueiredo L., Botelho R., Tornisielo V., 2015. Liquid chromatography–electrospray ionization tandem mass spectrometry and dynamic multiple reaction monitoring method for determining multiple pesticide residues in tomato. Food Chemistry, 175, 57-65.

Arthur C. L., Pawliszyn J. 1990. Solid phase microextraction with thermal desorption using fused silica optical fibers. *Analytical Chemistry*, 62(19), 2145-2148.

Awasthi M. D., 1986. Chemical treatments for the decontamination of brinjal fruit from residues of synthetic pyrethroids. *Journal of Pesticide Science* 17(2):89-92.

Awasthi M. D., 1993. Decontamination of insecticide residues on mango by washing and peeling. *Journal of Food Science and Technology* 30:132-133.

Aysal P., Ambrus A., Lehotay S. J., Cannavan A., 2007. Validation of an efficient method for the determination of pesticide residues in fruits and vegetables using ethyl acetate for extraction. *Journal of Environmental Science and Health* Part B, 42(5), 481-490.

Balinova A., Mladenova R., Shtereva D., 2007. Solid-phase extraction on sorbents of different retention mechanisms followed by determination by gas chromatography–mass spectrometric and gas chromatography–electron capture detection of pesticide residues in crops. *Journal of Chromatography* A, 1150(1-2), 136-144.

Barker S. A., Long A. R., Short C. R., 1989. Isolation of drug residues from tissues by solid phase dispersion. *Journal of Chromatography* A, 475(2), 353-361.

Bhushan C., Bhardwaj A., Misra S.S., 2013. State of pesticide regulations in India. Centre for Science and Environment, New Delhi, pp 1-72.

Cai D. W., 2008. Understand the role of chemical pesticides and prevent misuses of pesticides. Bulletin of Agricultural Science and Technology 1(6): 36-38.

Carneiro R. P., Oliveira F. A., Madureira F. D., Silva G., de Souza W. R., Lopes R. P., 2013. Development and method validation for determination of 128 pesticides in bananas by modified QuEChERS and UHPLC–MS/MS analysis. *Food Control*, 33(2), 413-423.

Chen Q., Fung Y., 2010. Capillary electrophoresis with immobilized quantum dot fluorescence detection for rapid determination of organophosphorus pesticides in vegetables. *Electrophoresis*, 31(18), 3107-3114.

Cho S. K., El-Aty A. A., Park K. H., Park J. H., Assayed M., Jeong Y. M., Shim J. H., 2013. Simple multiresidue extraction method for the determination of fungicides and plant growth regulator in bean sprouts using low temperature partitioning and tandem mass spectrometry. *Food Chemistry*, 136(3-4), 1414-1420.

Christia C., Bizani E., Christophoridis C., Fytianos K., 2015. Pesticide residues in fruit samples: Comparison of different QuEChERS methods using liquid chromatography–tandem mass spectrometry. *Environmental Science and Pollution Research*, 22(17), 13167-13178.

Crnogorac G., Schmauder S. and Schwack W. 2008. Trace analysis of dithiocarbamate fungicide residues on fruits and vegetables by hydrophilic interaction liquid chromatography/tandem mass spectrometry. *Rapid Communications in Mass Spectrometry*, 22(16), 2539-2546.

Daniel D., dos Santos V. B., Vidal D. T. R., do Lago C. L., 2015. Determination of halosulfuron-methyl herbicide in sugarcane juice and tomato by capillary electrophoresis–tandem mass spectrometry.*Food Chemistry*, 175, 82-84.

DARE, 2015. DARE/ICAR Annual report, 2014-15. pp 1-103.

Dzuman Z., Zachariasova M., Veprikova Z., Godula M., Hajslova J., 2015. Multi-analyte high performance liquid chromatography coupled to high resolution tandem mass spectrometry method for control of pesticide residues, mycotoxins, and pyrrolizidine alkaloids. *Analytica Chimica Acta*, 863, 29-40.

Fernandez Moreno J. L., GarridoFrenich A., Plaza Bolanos P., Martinez Vidal J. L., 2008. Multiresidue method for the analysis of more than 140 pesticide residues in fruits and vegetables by gas chromatography coupled to triple quadrupole mass spectrometry. *Journal of Mass Spectrometry*, 43(9), 1235-1254.

FICCI, 2013. Indian Agrochemical Industry: imperative of growth. 3rd National Agrochemical conclave. https://ficci.in/spdocument/20292/petro1.pdf?msclkid=5e7926d3b0e511ecada1bf97550ff925

Gilbert-Lopez B., Garcia-Reyes J. F., Fernandez-Alba A. R., Molina-Diaz A., 2010. Evaluation of two sample treatment methodologies for large-scale pesticide residue analysis in olive oil by fast liquid chromatography–electrospray mass spectrometry. *Journal of Chromatography* A, 1217(24), 3736-3747.

Grimalt S., Sancho J. V., Pozo O. J., Hernandez F., 2010. Quantification, confirmation and screening capability of UHPLC coupled to triple quadrupole and hybrid quadrupole time-of-flight mass spectrometry in pesticide residue analysis. *Journal of Mass Spectrometry*, 45(4), 421-436.

Gupta A., 2006 Pesticide residue in food commodities. *Agrobios* (India).

Helfrich L. A., 2009. Aquatic animals; a guide to reducing impacts on aquatic systems. http//publc.ext.vt.edu/420/420-013/420-013htm. Accessed on June 3, 2011.

Huskova R., Matisova E., Hrouzkova S., Svorc L., 2009. Analysis of pesticide residues by fast gas chromatography in combination with negative chemical ionization mass spectrometry. *Journal of Chromatography* A, 1216(35), 6326-6334.

Jallow M. F., Awadh D. G., Albaho M. S., Devi V. Y., Ahmad N., 2017. Monitoring of pesticide residues in commonly used fruits and vegetables in Kuwait. *International Journal of Environmental Research and Public Health*, 14(8), 833.

Kin C. M., Huat T. G., 2010. Head space solid-phase micro-extraction for the evaluation of pesticide residue contents in cucumber and strawberry after washing treatment. *Food Chemistry*, 123(3), 760-764.

Lehotay S. J., Mastovska K., Lightfield A. R., Gates R. A., 2010. Multi-analyst, multi-matrix performance of the QuEChERS approach for pesticide residues in foods and feeds using HPLC/MS/MS analysis with different calibration techniques. *Journal of AOAC International*, 93(2), 355-367.

Li J., Lu J., Qiao X., Xu Z., 2017. A study on biomimetic immunoassay-capillary electrophoresis method based on molecularly imprinted polymer for determination of trace trichlorfon residue in vegetables. *Food Chemistry*, 221, 1285-1290.

Liu S., Zheng Z., Wei F., Ren Y., Gui W., Wu H., Zhu G., 2010. Simultaneous determination of seven neonicotinoid pesticide residues in food by ultraperformance liquid chromatography tandem mass spectrometry. *Journal of Agricultural and Food Chemistry*, 58(6), 3271-3278.

Luke M. A., Froberg J. E., Masumoto H. T., 1975. Extraction and cleanup of organochlorine, organophosphate, organo-nitrogen, and hydrocarbon pesticides in produce for determination by gas-liquid chromatography. *Journal-Association of Official Analytical Chemists*, 58(5),1020-1026.

Navarro P., Perez A., Gabaldon J. A., Nunez-Delicado E., Puchades R., Maquieira A., Morais S., 2013. Detection of chemical residues in tangerine juices by a duplex immunoassay. *Talanta*, 116, 33-38.

NPIC, 2011. National pesticide information Center. http//npic.orst. edu/envir/efate. html, accessed June 3, 2011.

Pimentel D. 2009. Pesticides and pest control. In: Rajinder P, Dhawan A (eds) Integrated pest management: innovation-development process, vol 1. Springer, pp 83-87.

Rai A.B., 2014. Integrated pest management for vegetable crops. Indian Institute of Vegetable Research, Varanasi.

Rong L., Wu X., Xu J., Dong F., Liu X., Pan X., Zheng Y. 2017. Simultaneous determination of three pesticides and their metabolites in unprocessed foods using ultra-performance liquid chromatography-tandem mass spectrometry. *Food Additives & Contaminants*: Part A, 1-9.

Shamsipur M., Yazdanfar N., Ghambarian M., 2016. Combination of solid-phase extraction with dispersive liquid–liquid microextraction followed by GC–MS for determination of pesticide residues from water, milk, honey and fruit juice. *Food Chemistry*, 204, 289-297.

Sivaperumal P., Anand P., Riddhi L., 2015. Rapid determination of pesticide residues in fruits and vegetables, using ultra-high-performance liquid chromatography/ time-of-flight mass spectrometry. *Food Chemistry*, 168, 356-365.

Torbati M., Farajzadeh M. A., Torbati M., Nabil A. A. A., Mohebbi A., Mogaddam M. R. A., 2018. Development of salt and pH–induced solidified floating organic droplets homogeneous liquid–liquid microextraction for extraction of ten pyrethroid insecticides in fresh fruits and fruit juices followed by gas chromatography-mass spectrometry. *Talanta*, 176, 565-572.

Wang P., Yang X., Wang J., Cui J., Dong A., Zhao H., Li W., 2012. Multi-residue method for determination of seven neonicotinoid insecticides in grains using dispersive solid-phase extraction and dispersive liquid–liquid micro-extraction by high performance liquid chromatography. *Food Chemistry*, 134(3), 1691-1698.

Wang X., Tang Q., Wang Q., Qiao X., Xu Z., 2014. Study of a molecularly imprinted solid-phase extraction coupled with high-performance liquid chromatography for simultaneous determination of trace trichlorfon and monocrotophos residues in vegetables. *Journal of the Science of Food and Agriculture*, 94(7), 1409-1415.

Yu X., Yang, H., 2017. Pyrethroid residue determination in organic and conventional vegetables using liquid-solid extraction coupled with magnetic solid phase extraction based on polystyrene-coated magnetic nanoparticles. *Food Chemistry*, 217, 303-310.

Zhang H., Wang J., Li L., Wang Y. 2017. Determination of 103 pesticides and their main metabolites in animal origin food by QuEChERS and liquid chromatography–tandem mass spectrometry. *Food Analytical Methods*, 10(6), 1826-1843.

Chapter - 13

Sources of Pesticides Residues in Fruits and Vegetables

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Introduction

Fruits and vegetables play an essential part in a balanced diet and sustain the body's normal functioning by providing a staple source of essential vitamins and minerals. The vegetables and fruits diet has gained attention due to its protective role against chronic diseases and its beneficial effects on health status. However, the source of minerals and vitamins can become carriers of pesticides residue for ingestion by penetrating to a pulp via peel and translocating further to xylem and phloem (Bonmatin *et al*., 2015). Therefore, the consumer ingests the residue unintentionally along with the fruits and vegetables health-promoting nutrients. There is now increasing public concern over the health risks of fruit and vegetables consumption. In fact, the quality and yield of fruits and vegetables are threatened by the infestation of pests and diseases during production and storage levels, which necessitates pesticides. To meet the ever increasing population demand for fruits and vegetables with diminishing agricultural land, the use of pesticides has a long-standing. It plays a crucial role in protecting against various biotic stresses, viz., insects, microorganisms, and weeds that will enhance crop productivity. The Indian insecticide consumption is 76 % out of total pesticide as against 44 % worldwide. The pesticide used in fruits and vegetables accounts for 10–12 % (Kumari *et al*., 2003;Bhattacharyya *et al*.,2009). The pesticide application ensures the farmers and consumers for the year round quality production (Cooper and Dobson, 2007). Therefore, pesticide consumption has risen over the years due to its efficiency in controlling fruit and vegetable pest complex within a short period and minimum human resources requirement. Although pesticide application assures quality fruits and vegetable production, numerous pesticides are capable of causing severe health effects consumed in the wrong manner. Since fruits and some vegetables are mainly eaten raw and semi-processed, pesticide residues are the main risks that affect the safety of foods (Knežević *et al*., 2012; Swarnam and Velmurugan, 2013). In fact, humans are more exposed to pesticide residues on foods through diet than animal foods (Claeys *et al.*, 2011).

Regarding human toxicity, assessment of pesticide and fungicide residues indicates that exposure through food intake is 10^3 to 10^5 times higher than that induced by drinking water and inhalation (Margni *et al.*, 2002). In addition, they may cause adverse health effects on reproduction, immune or nervous systems, and cancer (Slowik- Borowiec *et al.*, 2016). However, with rapid economic development and improved people living standards, a series of pesticide residue incidents caused widespread concern, and pesticide residues are no longer ignored (Chu *et al.*, 2019; Deng *et al.*, 2019).

Effects of Pesticides

The incorrect selection, injudicious use of pesticides on agricultural commodities, or harvesting crops before the residues have washed off after application can lead to customer consumption of produce containing a high amount of pesticides residues exceeding the prescribed maximum residue limits (MRL)(Chen *et al.*, 2011). Numerous surveys and studies have reported that most pesticide residues in fruits and vegetables worldwide were below the residue threshold level (Kumari and John 2019). However, the latest scientific research has found that even with low-level or sub-threshold pesticide residues, non-persistent pesticides, such as diazinon, chlorpyrifos, and methyl parathion, may also cause neurodevelopmental disorders to children(González-Alzaga *et al.*, 2014),cancer,reproductive problems and genotoxic effects on adults under long-term exposure (Samsidar *et al.* 2018; Chen *et al.*, 2019). Among the insecticide group, the broad-spectrum carbamate pesticides and organophosphorus represents a risk to human health by inhibiting the acetylcholinesterase (Wesseling *et al.*, 2002; Bogialli *et al.*, 2004) that leads to acute impacts, such as headaches, nausea, skin and eye irritation, to the chronic effects, such as congenital disabilities, cancer, cardiovascular disease, development defects, diabetes, neurological and reproductive disorders (Bogialli *et al.*, 2004; Mostafalou and Abdollahi, 2013). In comparison, the low-polarity lipophilic pyrethroid pesticides possess low mammalian toxicity and short-term environmental persistence (Stefanelli *et al.*, 2009). In addition, pesticide application may also cause harm to other non-target organisms, including bees, birds, and fish, damage to the environmental in the form of contaminating turf and other plants, soil, water, and increased resistance in the target pest organisms (Köhler and Triebskorn, 2013). Recent studies by Gill *et al.* (2012) have implicated that excessive pesticides consumption has led to declines in the production of colony queens and changes the bee behavior accordingly.

Detection of Pesticides Residues on Samples

Considering the excess consumption of pesticides in agriculture, it is necessary to systematically check the risk of chemicals with specific toxicity in raw eaten food to ensure that the residues are safe for consumers dietary health. For plant-derived foods, several exposure assessment methods have been developed, including hazard index (HI), relative potency factor (RPF), and margin of exposure (MOE) (Alla *et al*., 2015; Narváez *et al*., 2020). In addition, different analytical methods such as ultra high-performance liquid chromatography-tandem mass spectrometry (UPLC-MS/MS) (Lacina *et al*., 2012); gas chromatography-tandem, mass spectrometry (Chen *et al*., 2013); high-performance liquid chromatography (Shuang *et al*., 2020; Umsza-Guez *et al*., 2021); liquid and gas chromatography coupled to tandem mass spectrometry (Golge *et al*., 2021) and surface-enhanced Raman spectroscopy (SERS) equipped with flexible substrate methylcellulose-decorated silver nanoparticles (MC/Ag NPs) film (Zhang *et al*., 2021) among others, play an essential role for the detection of pesticide residues in foods. Chemical and physical detection methods are highly accurate; nevertheless, they require professional detection personnel, time-consuming and costly. Therefore, a simple, rapid, non-destructive, inexpensive, high sensitivity with good reproducibility and repeatability specific detection method must be developed (Cui *et al*., 2018; Jia *et al*., 2019). A recent, quick, high accuracy, and non-destructive technology, viz., fluorescence spectrum, was employed for the detection of paclobutazol in apple juice (Yu *et al*., 2020); Tang *et al*. (2021) utilized an electronic nose for the detection of multiple pesticides residues on apples with 90-94% accuracy within a short measurement time of 2 minutes and triazole that deteriorates the nutrition and quality of the wine was detected by Xiao *et al*. (2020) using an electronic tongue. Similarly, pesticides residue on garlic chives (Allium tuberosum) are accurately detected by He *et al*. (2021) using short wave infrared hyperspectral images.

Ways of Pesticides Contamination on Fruits and Vegetables

The persistent existence of undesirable pesticides has resulted from the irrational application during crop cultivation, which results in crops, soils, and waterways pesticide residues (Ward *et al*., 1993). The pesticides residues are found on food commodities in several ways.

1. Application of pesticides on farms

The use of pesticides and fungicides to achieve maximum crop production in modern farming practices is now considered to be an integral part of the agricultural industry.

In developing countries, poor agricultural practices are the significant sources of pesticide poisoning through dermal and oral ingestion (Abbassy, 2017; Kumari and John, 2018; Mohamed *et al.*, 2019). The majority of the applied chemical contaminate soil and aquifers and affected several organisms. Additionally, spray drift from neighboring plots and or cross-contamination in the processing of the crops can even result in pesticides residues (Lozowicka, 2015). Farm fresh fruits and vegetables have a higher concentration of pesticides residue than supermarkets due to pre-processing (Sinha *et al.*, 2012; Kumari and John, 2019). For instance, 75–80 % of the pesticides consumption in Andaman and Nicobar island is for vegetable cultivation alone. Among them, green chilies, crucifers, cucurbits, okra, and brinjal has detectable residues of organochlorine (OC), organophosphorus (OP), and synthetic pyrethroid (SP) compounds at 14.5 %, 53.6 %, and 31.8 %, respectively. The heavy consumption of OP compounds in vegetable productions can be evident in its residue. For instance, green chilies, cucurbits, and cruciferous vegetables carried 41% and 44% residue of OP and OC, respectively. However, α-cypermethrin was the predominant pesticide residue in Andaman vegetables (Swarnam and Velmurugan, 2013).

2. Post harvest fumigation treatments

The horticultural crops are highly export commodities; hence the occurrence of pests in horticultural produce has been the center of attention of many procedures and treatments to prevent continuous damage of fruits and vegetables or accidental movement of pests from one area to another. To avoid havoc and rejection of commodities, the commodities are treated with pesticides. The postharvest treatment is very important for facilitating national and international trade of horticultural commodities. Fumigants are the choicest tool for disinfecting postharvest arthropod pests and products in quarantine because of their low cost and efficacy compared to alternative methods (Bond and Monro, 1984).The incidence of fruit flies in fruits and vegetables are effectively removed by fumigation with methyl bromide, ethylene dibromide, and ethylene chlorobromide (Seo *et al.*, 1970). However, under the United Nations Montreal Protocol, the use of Methyl bromide (MB), the fumigant of choice, was restricted because of its deleterious impact on the ozone layer (UNEP, 2006). The post restriction of methyl bromide promoted the application of phosphine (PH3) as a fumigant in stored products; however many postharvest insect pests have developed tolerance or resistance (Daglish, 2004; Opit *et al.*, 2012). In addition, the slow speed of action and detectable toxic residues can be problematic (Fields and White, 2002). Other fumigants that have either been adopted or are under investigation as substitutes for phosphine, including sulfuryl fluoride, carbonyl sulfide, nitric oxide and sulfur dioxide (Lichter *et al.*, 2000; Goletti and Samman, 2002; Athanassiou *et al.*, 2012; Yang and Liu, 2017). The newly discovered fumigant-Nitric oxide (NO) is effective against a wide range of post harvest pests, both external and internal feeders (Yang and Liu, 2017) *viz*., thrips and spotted wing drosophila (SWD) in sweet cherries (Liu 2014; Liu and Yang, 2016); strawberries SWD (Yang and Liu, 2018); lettuce aphid, (*Nasonovia ribisnigri*) and western flower thrips (*Frankliniella occidentalis*) (Yang and Liu, 2019); dried apricot moth (Chen *et al*., 2021); navel orangeworm (*Amyelois transitella*) in walnut (Yang *et al*., 2021) to name a few. To control insects and microorganisms on stored almonds, both NO and NO_2 have antimicrobial properties. NO inhibits the growth of some microorganisms, including bacteria and fungi (Deppisch *et al*., 2016). In addition, NO fumigation is effective against *Salmonella* species and *Aspergillus* species in almonds (Oh and Liu, 2020). NO fumigation at various concentrations could effectively decrease the number of microorganisms on dried apricots during storage (Chen *et al*., 2021).

The high moisture content in fruits and vegetables accelerates the rapid quality deterioration of the fresh produce. Hence, fumigation using nitrite oxide is employed for retaining and improvement of product quality, such as inhibition of enzymatic browning in fresh pistachios (Gheysarbigi *et al*., 2020); enhancement of the antioxidant system, inhibition of ethylene biosynthesis, induced defense system, activated CBFs pathway, and regulated sugar and energy metabolisms in red raspberries and dried apricots (Shi *et al*., 2019; Zhang *et al*., 2020, Chen *et al*., 2021). In dried apricot, Chen *et al*. (2021) reported that NO fumigated apricot displayed lower levels of total color change, degree of browning, and decline of nutrients. Nonetheless, NO had no safety concerns regarding residues after 24 h after fumigation when properly terminated with nitrogen flushing (Yang and Liu, 2017).

In storage potatoes, the plant regulator and herbicide chlorpropham (CIPC) has been widely used as the anti-sprouting agent over the past few decades. However, the European Union and the UK decided not to authorize the renewal of CIPC in 2019, prompting the value chain to find alternative treatments. The pre-harvest application of maleic hydrazide (MH) and pos tharvest applications of 3-decen-2-one, 1,4-dimethyl naphthalene (1,4-DMN), and 3-decen-2-one are good alternatives anti-sprouting agents. However, MH has resulted in residues in the potatoes (Visse-Mansiaux *et al*., 2021).

3. Post harvest chemical treatments

The fruits and vegetables are surface coated with fungicides and chemicals before marketing or storage under ambient or refrigerated conditions, which facilitates the reduction of chilling injury under refrigeration. In addition, the shelf life is prolonged by the application of plant growth regulators, including various fungicides, to control rots. Sodium o-phenylphenate (SOPP), commercially known as 'Dowcide A', has long been used to prevent decay in citrus fruit; however this chemical residues in 'Pineapple' and 'Valencia' oranges (Hayward and Grierson, 1960). In the same manner, Miao *et al*. (2018) treated the cabbage with azoxystrobin, tebuconazole, carbendazim, chlorothalonil, cyprodinil, and fluazinam to protect against fungal post harvest diseases, especially caused by *Peronospor parasitica*, *Sclerotinia sclerotiorum,* and *Botrytis cinerea;* the chlorothalonil treated residues accumulated more on the surface due to its non-systemic nature. It is reported that the fungicide residue is often higher when it is applied in wax (Gutter, 1981).

Other indirect sources

The use of quality irrigation water in fruits and vegetable production is constrained in most arid and semi-arid areas (Amoah *et al*., 2006; Al-Nasir *et al*., 2020; Ishaq *et al*., 2020). As a result, the heavily polluted untreated water, such as urban drains, was often used as irrigation water (Amoah *et al*., 2006). This has become one of the major concerns in developing and underdeveloped countries. Reclaimed irrigated vegetable, fruit crops, and soil had a higher concentration of chlorpyrifos and emamectin, lindane, endosulfan, lambda cyhalothrin, and dichloro-diphenyl-trichloroethane, carbamazepine (CBZ) (Amoah *et al*., 2006; Shenker *et al*., 2011; Al-Nasir *et al*., 2020; Ishaq *et al*., 2020). Besides, Fernandes *et al*. (2011) concluded the atmospheric drifting and soil leaching of organochlorine pesticides (OCP) are important sources of residue on organic strawberry farming.

Table1: Pesticides residues in fruits and vegetables

S. No.	Pesticide group	Pesticides	Crop	Pesticides residue (ppm)	References
1	Organochlorine				
		Endosulphan	Crucifers	0.190	Swarnam and Velmurugan (2013)
			Cucurbits	0.130	Swarnam and Velmurugan (2013)
			Green chillies	0.090	Swarnam and Velmurugan (2013)
			Okra	0.170	Swarnam and Velmurugan (2013)

			Tomato	0.040	Knežević *et al*. (2012)
2	Organophosphorus				
		Acephate	Bell pepper	0.040	Chu *et al*. (2019)
		Azinphos-methyl	Peach	0.320	Knežević *et al*. (2012)
		Chlorpyrifos	Apple	BDL to 0.009	Kumari and John (2019)
			Apple	0.070 ± 0.085	Tzatzarakis *et al*. (2020)
			Bell pepper	0.080	Chu *et al*.(2019)
			Cabbage	0.003 to 0.008	Kumari and John (2019)
			Cauliflower	0.008 to 0.033	Kumari and John (2019)
			Grapes	BDL to 0.013	Kumari and John (2019)
			Lettuce	0.710	Knežević *et al*. (2012)
			Orange	0.670	Knežević *et al*. (2012)
			Pear	0.078 ± 0.081	Asi *et al*. (2020)
			Peas	BDL to 0.010	Kumari and John (2019)
			Potato	0.370	Knežević *et al*. (2012)
			Potatoes	BDL to 0.005	Kumari and John (2019)
		Diazinon	Apple	0.009	Tzatzarakis *et al*. (2020)
			Apple	0.090	Knežević *et al*. (2012)

			Orange	0.280	Knežević *et al.* (2012)
			Pear	0.080	Knežević *et al.* (2012)
		Dichlorvos	Bell pepper	0.100	Chu *et al.* (2019)
			Apple	0.007	Tzatzarakis *et al.* (2020)
		Dimethoate	Bell pepper	0.890	Chu *et al.* (2019)
			Eggplant	0.100	Knežević *et al.* (2012)
			Lettuce	0.240	Knežević *et al.* (2012)
			Pepper	0.050	Knežević *et al.* (2012)
		Ethion	Apple	0.002 to 0.010	Kumari and John (2019)
			Cabbage	BDL to 0.006	Kumari and John (2019)
			Cauliflower	BDL to 0.005	Kumari and John (2019)
			Grape	BDL to 0.007	Kumari and John (2019)
			Peas	BDL to 0.007	Kumari and John (2019)
			Potatoes	BDL to 0.007	Kumari and John (2019)
		Ethoprophos	Bell pepper	0.090	Chu *et al.* (2019)
		Isazofos	Bell pepper	0.010	Chu *et al.* (2019)
		Isocarbophos	Bell pepper	0.030	Chu *et al.* (2019)
		Isofenphos-methyl	Bell pepper	0.010	Chu *et al.* (2019)
		Malathion	Cabbage	0.005 to 0.012	Kumari and John (2019)
			Cauliflower	BDL to 0.015	Kumari and John (2019)

			Gherkin	0.030	Golge *et al*. (2021)
			Grapes	BDL to 0.007	Kumari and John (2019)
			Peas	BDL to 0.014	Kumari and John (2019)
			Potatoes	BDL to 0.007	Kumari and John (2019)
		Methamidophos	Bell pepper	0.090	Chu *et al*. (2019)
		Methidathion	Bell pepper	1.070	Chu *et al*. (2019)
			Grapefruit	0.260	Knežević *et al*. (2012)
			Lemon	0.600	Knežević *et al*. (2012)
			Orange	0.330	Knežević *et al*. (2012)
		Monocrotophos	Bell pepper	0.050	Chu *et al*. (2019)
		Omethoate	Apple	0.008	Tzatzarakis *et al*. (2020)
		Omethoate	Bell pepper	0.390	Chu *et al*. (2019)
		Parathion	Apple	BDL to 0.007	Kumari and John (2019)
			Cabbage	BDL to 0.007	Kumari and John (2019)
			Cauliflower	BDL to 0.008	Kumari and John (2019)
			Grapes	BDL to 0.008	Kumari and John (2019)
			Peas	BDL to 0.007	Kumari and John (2019)
			Potatoes	BDL to 0.006	Kumari and John (2019)
		Parathion-methyl	Bell pepper	0.080	Chu *et al*. (2019)
		Phorate	Bell pepper	0.020	Chu *et al*. (2019)

		Phosalone	Apple	0.400	Knežević *et al.* (2012)
		Triazophos	Vegetables	0.020 -1.700	Swarnam and Velmurugan (2013)
			Apple	0.005 ± 0.004	Tzatzarakis *et al.* (2020)
			Cabbage	BDL to 0.011	Kumari and John (2019)
			Cauliflower	BDL to 0.007	Kumari and John (2019)
			Grapes	BDL to 0.005	Kumari and John (2019)
			Peas	BDL to 0.006	Kumari and John (2019)
			Potatoes	BDL to 0.004	Kumari and John (2019)
3.	Pyrethroid				
		α-Cypermethrin	Apple	BDL to 0.043	Kumari and John (2019)
			Brinjal	0.030	Swarnam and Velmurugan (2013)
			Cabbage	BDL to 0.017	Kumari and John (2019)
			Cauliflower	0.004 to 0.025	Kumari and John (2019)
			Cucurbits	0.030	Swarnam and Velmurugan (2013)
			Grapes	BDL to 0.017	Kumari and John (2019)
			Green Chillies	0.090	Swarnam and Velmurugan (2013)
			Okra	0.020	Swarnam and Velmurugan (2013)
			Peas	BDL to 0.016	Kumari and John (2019)

			Potatoes	BDL to 0.036	Kumari and John (2019)
		Bifenthrin	Bell pepper	0.680	Chu *et al*. (2019)
		Cyfluthrin	Bell pepper	0.040	Chu *et al*. (2019)
			Grapes	0.220	Knežević *et al*. (2012)
		Cypermethrin	Bell pepper	0.720	Chu *et al*. (2019)
			Grapes	0.700	Knežević *et al*. (2012)
			Pear	0.700	Knežević *et al*. (2012)
		Etofenprox	Apple	0.077 ± 0.111	Tzatzarakis *et al*. (2020)
		Fenpropathrin	Bell pepper	0.520	Chu *et al*. (2019)
		Lambda-Cyhalothrin	Bell pepper	0.340	Chu *et al*. (2019)
		Lambda-Cyhalothrin	Grapes	0.020	Knežević *et al*. (2012)
4.	Carbamate				
		Carbaryl	Apple	0.077 ± 0.048	Tzatzarakis *et al*. (2020)
		Carbofuran	Bell pepper	0.140	Chu *et al*. (2019)
		Methomyl	Apple	0.021 ± 0.016	Tzatzarakis *et al*. (2020)
			Bell pepper	0.120	Chu *et al*. (2019)
		Pirimicarb	Apple	0.021 ± 0.017	Tzatzarakis *et al*. (2020)
			Gherkin	0.010 to 0.098	Golge *et al*. (2021)
5.	Neonicotinoid				
		Acetamiprid	Gherkin	0.015 to 0.190	Golge *et al*. (2021)
		Aldicarb	Bell pepper	0.030	Chu *et al*. (2019)

		Imidachloprid	Apple	0.145 ± 0.288	Tzatzarakis *et al.* (2020)
		Thiachloprid	Apple	0.034 ± 0.035	Tzatzarakis *et al.* (2020)
6.	Avermectin				
		Aabamectin	Orange	0.030 ± 0.004	Acoglu and Omeroglu (2021)
7.	Acaricide				
		Etoxazole	Orange	0. 082 ± 0.025	Acoglu and Omeroglu (2021)
		Tebufenpyrad	Apple	0.100 ± 0.071	Tzatzarakis *et al.* (2020)
8.	Fungicidal pesticides				
		Boscalid	Apple	0.105 ± 0.062	Tzatzarakis *et al.* (2020)
		Captan	Apple	BDL to 0.036	Kumari and John (2019)
			Cabbage	BDL to 0.002	Kumari and John (2019)
			Cauliflower	BDL to 0.013	Kumari and John (2019)
			Grapes	BDL to 0.015	Kumari and John (2019)
			Potatoes	BDL to 0.013	Kumari and John (2019)
		Carbendazim	Apple	0.061 ± 0.138	Tzatzarakis *et al.* (2020)
			Pear	0.007 ± 0.008	Asi *et al.* (2020)
		Chlorothalonil	Gherkin	0.010 to 0.250	Golge *et al.* (2021)
		Cyprodinil	Apple	0.013 ± 0.001	Tzatzarakis *et al.* (2020)
		Diffenconazole	Pear	0.186 ± 0.274	Asi *et al.* (2020)

		Ethirimol	Grapes	0.002 to 0.390	Si *et al*. (2021)
		Fluopyram	Apple	0.169 ± 0.181	Tzatzarakis *et al*. (2020)
		Imazalil	Banana	1.240	Knežević *et al*. (2012)
			Grapefruit	3.340	Knežević *et al*. (2012)
			Lemon	1.650	Knežević *et al*. (2012)
			Lettuce	3.070	Knežević *et al*. (2012)
			Mandarin	0.530	Knežević *et al*. (2012)
			Orange	2.113 ± 0.475	Acoglu and Omeroglu (2021)
			Oranges	27.90	Knežević *et al*. (2012)
		Iprodione	Lettuce	6.410	Knežević *et al*. (2012)
		Iprodione	Gherkin	0.010 to 0.020	Golge *et al*. (2021)
		Myclobutanil	Apple	0.007 ± 0.008	Tzatzarakis *et al*. (2020)
		Procymidone	Cucumber	0.100	Knežević *et al*. (2012)
			Lettuce	8.410	Knežević *et al*. (2012)
			Pepper	0.040	Knežević *et al*. (2012)
			Strawberry	0.220	Knežević *et al*. (2012)
		Pyraclostrobin	Apple	0.133 ± 0.145	Tzatzarakis *et al*. (2020)
		Thiabendazole	Apple	2.130	Knežević *et al*. (2012)

			Grapefruit	1.630	Knežević *et al.* (2012)
			Lemon	1.400	Knežević *et al.* (2012)
			Orange	10.600	Knežević *et al.* (2012)
		Thiophanate methyl	Apple	0.087 ± 0.073	Tzatzarakis *et al.* (2020)
		Thiophanate methyl	Orange	0.110 ± 0.030	Acoglu and Omeroglu (2021)
		Tolylfluanid	Apple	10.740	Knežević *et al.* (2012)
			Pear	0.140	Knežević *et al.* (2012)
		Vinklozolin	Lettuce	3.270	Knežević *et al.* (2012)
9.	Growth Regulator				
		Buprofezin	Orange	0.189 ± 0.047	Acoglu and Omeroglu (2021)
		Chlorpropham	Potato	2.100	Knežević *et al.* (2012)
		Pyriproxifen	Apple	0.006 ± 0.003	Tzatzarakis *et al.* (2020)

*BDL: Below detection level

Conclusion

Quality is the primary driving force in vegetables and fruits marketing and for food safety. Hence, the food regulatory authorities, suppliers, and consumers faced severe problems of pesticide residues on commodities. It has been one of the major requirements to establish and sustain a viable percentage of the market, both inside and outside of the country. Since the farmers tend to use pesticides in combination or overlapping of pesticides application with the waiting period, multiple residues of pesticides were detected in vegetables and fruits (Petersen *et al.*, 2013; Authority *et al.*, 2021; Golge *et al.*, 2021). Amongst the pesticides group, the chlorpyrifos of organophosphorus pesticides group dominates residue in vegetables and fruits, contributing to 42 %, followed by triazophos and profenophos (Fytianos *et al*., 2007; Hjorth *et al*., 2011; Swarnam and Velmurugan, 2013; Chu *et al*., 2019). Acetamiprid of neonicotinoid compounds in bell pepper (Golge *et al*., 2018); carbendazim, chlorpyrifos, and thiacloprid in apple (El Hawari *et al*., 2019; Tzatzarakis *et al*., 2020); chlorothalonil (32%), acetamiprid (16.3%), and metalaxyl and its enantiomer metalaxyl-M (4.9%) in gherkin ((Golge *et al*., 2021) and pyrethroid (El Hawari *et al*., 2019) were also detected. In cucumber, Bakırcı *et al*. (2014) identified metalaxyl. Furthermore, Narváez *et al*. (2020) detected fludioxonil, mepanipyrim, and ethoxyquin residues in the pear juices, including several European Union unapproved pesticides such as ethoxyquin, triazophos, and bifenthrin.

In a developing country, where the maximum population is involved in agriculture, the risk of pesticides exposure can be minimized by increased understanding and awareness of the adverse effects of pesticides on health and environment, correct application techniques, use of appropriate spraying equipment, and insufficient storage practices; decontamination by the applications of innovative food processing technologies, including cold plasma (CP), high-pressure processing (HPP), pulsed electric fields (PEF), supercritical carbon dioxide (SC-CO2), and ultrasound (USN) processing, electrolyzed oxidizing water (EOW) (Gavahian *et al*., 2020; Yang *et al*., 2020; Sun *et al*., 2022).

An alternative to pesticides in the agricultural system is organic farming that utilizes biopesticides (Benbrook, 2021). Additionally, the presence of natural enemies, the distribution of pest population, active season to grow, expected weather patterns (Jongen, 2005), and integrated pest management products detected a lower percentage of pesticides (47 %) which is even lower at 23 % in biological goods (Baker *et al*., 2002). In this line, the organic pear juices collected by Narváez *et al*. (2020) from the Italian market place showed significantly fewer residues than conventional samples.

Numerous scarcities still exist in the post harvest management and processing of fruits and vegetables in developing countries. The use of chemicals in post harvest management is harmful to the environment as well as the human body. Hence, the effective, non-chemical method for reducing post-harvest diseases like curing in pack sterilization (Bonnechère *et al*., 2012); ozonation (Horvitz and Cantalejo, 2014) , and utilization of microbial agents possessing anti-fungal effects such as *C. pyralidae* Y1117 and *P. kluyveri* Y1125 (Mewa-Ngongang *etal*., 2018); *Saccharomyces* sp, *Hanseniaspora uvarum*(Capozzi *et al*., 2019) and *Candida zemplinina* (Russo *et al*., 2020) has increased its acceptance worldwide.

The consumption of pesticides residues on fruits and vegetables can be effectively reduced by the washing fresh produce with alkaline solutions (Wu *et al*., 2019) such as 10 % sodium carbonate solution (Na2CO3), 8-10 % vinegar, or acetic acid solutions (CH3COOH), 10 % table salt (NaCl) in combination with tap water; 10 % sodium hydroxide (NaOH) solution (Asi *et al*., 2020; Acoglu and Omeroglu, 2021); chlorine dioxide (Chen *et al*., 2014); essential oils (Liu *et al*., 2014) and NO fumigation with proper levels of NO and NO2 has the potential to safely and effectively control insect pests and microorganisms (Liu *et al*., 2016).

Furthermore, the chlorpyrifos pesticides were comparatively easier to remove from food commodities than pyrethroid pesticides (Wu *et al*., 2019). Therefore, regulation of pesticides is necessary to ensure they do not present unacceptable risks to humans, animals, or the environment. The overall optimization of pesticide handling by following the existing regulations could reduce the adverse effects of pesticides on human health and the environment (Damalas and Eleftherohorinos, 2011).

References

Abbassy, M. M. S. 2017. Farmer's Knowledge, Attitudes and Practices, and their exposure to pesticide residues after application on the vegetable and fruit crops. Case study: North of Delta, Egypt. *Journal of Environmental & Analytical Toxicology*, **7**(510): 2161-0525.

Acoglu, B. and Omeroglu, P. Y. 2021. Effectiveness of different types of washing agents on reduction of pesticide residues in orange (*Citrus sinensis*). *LWT*, **147**: 111690.

Alla, S. A. G., Loutfy, N. M., Shendy, A. H. and Ahmed, M. T. 2015. Hazard index, a tool for a long term risk assessment of pesticide residues in some commodities, a pilot study. *Regulatory Toxicology and Pharmacology*, **73**(3): 985-991.

Al-Nasir, F. M., Jiries, A. G., Al-Rabadi, G. J., Alu'datt, M. H., Tranchant, C. C., Al-Dalain, S. A., and Al-Dmour, R. S. 2020. Determination of pesticide residues in selected citrus fruits and vegetables cultivated in the Jordan Valley. *LWT*, **123**: 109005.

Amoah, P., Drechsel, P., Abaidoo, R. C. and Ntow, W. J. 2006. Pesticide and pathogen contamination of vegetables in Ghana's urban markets. *Archives of environmental contamination and toxicology*, **50**(1): 1-6.

Asi, M. R., Kali, S., Riaz, M. A., Waseem, A., Iqbal, M. M., Ahmad, N. and Zafar, M. I. 2020. Comparative efficacy of mitigation techniques for the detoxification of *Prunus persica* (L.) from selected pesticide residues. *Environmental Science and Pollution Research*, **27**(32):39786-39794.

Athanassiou, C. G., Phillips, T. W., Aikins, M. J., Hasan, M. M. and Throne, J. E. 2012. Effectiveness of sulfuryl fluoride for control of different life stages of stored-product psocids (Psocoptera). *Journal of economic entomology*, **105**(1): 282-287.

Authority, E. F. S., Cabrera, L. C., and Pastor, P. M. 2021. The 2019 European Union report on pesticide residues in food. *EFSA Journal*, *19*(4).

Baker, B. P., Benbrook, C. M., Iii, E. G. and Benbrook, K. L. 2002. Pesticide residues in conventional, integrated pest management (IPM)-grown and organic foods: insights from three US data sets. *Food Additives and Contaminants*, **19(**5): 427-446.

Bakırcı, G. T., Acay, D. B. Y., Bakırcı, F., and Ötleş, S. 2014. Pesticide residues in fruits and vegetables from the Aegean region, Turkey. *Food chemistry*, *160*, 379-392.

Benbrook, C., Kegley, S. and Baker, B. 2021. Organic Farming Lessens Reliance on Pesticides and Promotes Public Health by Lowering Dietary Risks. *Agronomy*, **11**(7): 1266.

Bhattacharyya, A., Barik, S. R. and Ganguly, P. 2009. New pesticide molecules, formulation technology and uses: Present status and future challenges. *The Journal of Plant Protection Sciences*, **1**(1): 9-15.

Bogialli, S., Curini, R., Di Corcia, A., Nazzari, M. and Tamburro, D. 2004. A simple and rapid assay for analyzing residues of carbamate insecticides in vegetables and fruits: hot water extraction followed by liquid chromatography-mass spectrometry. *Journal of agricultural and food chemistry*, **52(**4): 665-671.

Bond, E. J. and Monro, H. A. U.1984. *Manual of fumigation for insect control* (Vol. 54). Rome: FAO.

Bonmatin, J. M., Giorio, C., Girolami, V., Goulson, D., Kreutzweiser, D. P., Krupke, C. and Tapparo, A. 2015. Environmental fate and exposure; neonicotinoids and fipronil. *Environmental Science and Pollution Research*, **22(**1): 35-67.

Bonnechère, A., Hanot, V., Jolie, R., Hendrickx, M., Bragard, C., Bedoret, T. and Van Loco, J. 2012. Effect of household and industrial processing on levels of five pesticide residues and two degradation products in spinach. *Food Control*, **25**(1): 397-406.

Capozzi, V.; Berbegal, C.; Tufariello, M.; Grieco, F. and Spano, G. 2019. Impact of co-inoculation of *Saccharomyces cerevisiae*, *Hanseniaspora uvarum* and *Oenococcus* *oeni autochthonous* strains in controlled multi-starter grape must fermentations. *LWT*, **109**: 241–249.

Chen C, Qian T, Tao C, Li C and Li Y. 2011. Evaluation of pesticide residues in fruits and vegetables from Xiamen, China. *Food Control,* **22**: 1114-1120.

Chen, Q., Wang, Y., Chen, F., Zhang, Y. and Liao, X. 2014. Chlorine dioxide treatment for the removal of pesticide residues on fresh lettuce and in aqueous solution. *Food control*, **40**: 106-112.

Chen, X., Bian, Z., Hou, H., Yang, F., Liu, S., Tang, G. and Hu, Q. 2013. Development and validation of a method for the determination of 159 pesticide residues in tobacco by gas chromatography–tandem mass spectrometry. *Journal of agricultural and food chemistry*, **61**(24): 5746-5757.

Chen, Y., Deng, H., Zhang, J., Tiemur, A., Wang, J. and Wu, B. 2021. Effect of nitric oxide fumigation on microorganism and quality of dried apricots during storage. *Journal of Food Processing and Preservation*, e15725.

Chen, Z., Xu, Y., Li, N., Qian, Y., Wang, Z. and Liu, Y. 2019. A national-scale cumulative exposure assessment of organophosphorus pesticides through dietary vegetable consumption in China. *Food Control*, **104**: 34-41.

Chu, Z., Zhuang, M., Li, S., Xiao, P., Li, M., Liu, D. and Zhao, J. 2019. Residue levels and health risk of pesticide residues in bell pepper in Shandong. *Food Additives and Contaminants: Part A*, **36**(9): 1385-1392.

Claeys, W. L., Schmit, J. F., Bragard, C., Maghuin-Rogister, G., Pussemier, L. and Schiffers, B. 2011. Exposure of several Belgian consumer groups to pesticide residues through fresh fruit and vegetable consumption. *Food control*, **22**(3-4): 508-516.

Cooper, J. and Dobson, H. 2007. The benefits of pesticides to mankind and the environment. *Crop Protection*, **26**(9): 1337-1348.

Cui, S., Ling, P., Zhu, H., and Keener, H. M. 2018. Plant pest detection using an artificial nose system: A review. *Sensors*, **18**(2): 378.

Daglish, G. J. 2004. Effect of exposure period on degree of dominance of phosphine resistance in adults of Rhyzopertha dominica (Coleoptera: Bostrychidae) and Sitophilus oryzae (Coleoptera: Curculionidae). *Pest Management Science: formerly Pesticide Science*, **60**(8): 822-826.

Damalas, C. A. and Eleftherohorinos, I. G., 2011. Pesticide exposure, safety issues, and risk assessment indicators. *International Journal of Environmental Research and Public Health*, **8**(5): 1402-1419.

Deng, Q., Sun, L. and Zhu, T. 2019. Evaluation of an alternative fluorinated chitosan as a QuEChERS adsorbent for pesticide residue analysis in apple samples. *Analytical Methods*, **11(**27): 3460-3466.

Deppisch, C., Herrmann, G., Graepler-Mainka, U., Wirtz, H., Heyder, S., Engel, C. and Riethmüller, J. 2016. Gaseous nitric oxide to treat antibiotic resistant bacterial and fungal lung infections in patients with cystic fibrosis: a phase I clinical study. *Infection*, **44(**4): 513-520.

El Hawari, K., Mokh, S., Al Iskandarani, M., Halloum, W. and Jaber, F. 2019. Pesticide residues in Lebanese apples and health risk assessment. *Food Additives and Contaminants: Part B*, **12(**2): 81-89.

Fernandes, V. C., Domingues, V. F., Mateus, N. and Delerue-Matos, C. 2011. Organochlorine pesticide residues in strawberries from integrated pest management and organic farming. *Journal of Agricultural and Food Chemistry*, **59(**14): 7582-7591.

Fields, P. G. and White, N. D. 2002. Alternatives to methyl bromide treatments for stored-product and quarantine insects. *Annual review of entomology*, **47**(1): 331-359.

Fytianos, K., Drimaropoulou, G., Raikos, N., Theodoridis, G. and Tsoukali, H. 2007. Headspace solid-phase microextraction for the gas chromatographic analysis of organophosphorus insecticides in vegetables. *Journal of AOAC International*, **90**(6): 1677-1681.

Gavahian, M., Pallares, N., Al Khawli, F., Ferrer, E. and Barba, F. J. 2020. Recent advances in the application of innovative food processing technologies for mycotoxins and pesticide reduction in foods. *Trends in Food Science and Technology*.

Gheysarbigi, S., Mirdehghan, S. H., Ghasemnezhad, M. and Nazoori, F. 2020. The inhibitory effect of nitric oxide on enzymatic browning reactions of in-package fresh pistachios (*Pistacia vera* L.). *Postharvest Biology and Technology*, **159**: 110998.

Gill RJ, Ramos-Rodriguez O and Raine NE. 2012. Combined pesticide exposure severely affects individual and colony-level traits in bees. *Nature,* **491**: 105-108.

Goletti, F. and Samman, E. 2002. Post-Harvest Systems in World Agriculture. *Crop Post-Harvest: Science and Technology: Principles and Practice*, **1**:1-34.

Golge, O., Cinpolat, S. and Kabak, B. 2021. Quantification of pesticide residues in gherkins by liquid and gas chromatography coupled to tandem mass spectrometry. *Journal of Food Composition and Analysis*, **96**: 103755.

Golge, O., Hepsag, F. and Kabak, B. 2018. Health risk assessment of selected pesticide residues in green pepper and cucumber. *Food and chemical toxicology*, **121:** 51-64.

González-Alzaga, B., Lacasaña, M., Aguilar-Garduño, C., Rodríguez-Barranco, M., Ballester, F., Rebagliato, M. and Hernández, A. F. 2014. A systematic review of neurodevelopmental effects of prenatal and postnatal organophosphate pesticide exposure. *Toxicology letters*, **230**(2): 104-121.

Gutter, Y.1981. Investigation on new postharvest fungicide in Israel. *Proceeding International Society of Citri*culture, Japan, Vol. 2, pp. 810–811.

Hayward, F. W. and Grierson, W. 1960. Fungicide Residues, Effect of Treatment Conditions on O-Phenylphenol Residues in Oranges. *Journal of Agricultural and Food Chemistry*, **8(**4): 308-310.

He, W., He, H., Wang, F., Wang, S. and Lyu, R. 2021. Non-destructive detection and recognition of pesticide residues on garlic chive (Allium tuberosum) leaves based on short wave infrared hyperspectral imaging and one-dimensional convolutional neural network. *Journal of Food Measurement and Characterization*, 1-11.

Hjorth, K., Johansen, K., Holen, B., Andersson, A., Christensen, H. B., Siivinen, K..and Toome, M. 2011. Pesticide residues in fruits and vegetables from South America—a Nordic project. *Food Control*, **22**(11): 1701–1706.

Horvitz, S. and Cantalejo, M.J. 2014. Application of ozone for the postharvest treatment of fruits in fruits and vegetables from South America—a Nordic project. *Food Control*, **22**(11): 1701–1706.

Ishaq, M., Sultana, N., Ikram, M., Iqbal, A., Shah, F., Hamayun, M. and Hussain, A. 2020. Occurrence of heavy metals and pesticide residues in tomato crop: a threat to public health. *Arabian Journal of Geosciences*, **13**(14): 1-11.

Jia, W., Liang, G., Jiang, Z. and Wang, J. 2019. Advances in electronic nose development for application to agricultural products. *Food Analytical Methods*, **12**(10): 2226-2240.

Jongen, W. (Ed.).2005. Improving the safety of fresh fruit and vegetables. *Elsevier.*

Knežević, Z., Serdar, M. and Ahel, M. 2012. Risk assessment of the intake of pesticides in Croatian diet. *Food Control*, **23**(1): 59-65.

Köhler H and Triebskorn R. 2013. Wildlife ecotoxicology of pesticides: can we track effects to the population level and beyond? *Science,* **341**: 759-765.

Kumari, B., Kumar, R., Madan, V. K., Singh, R., Singh, J. and Kathpal, T. S. 2003. Magnitude of pesticidal contamination in winter vegetables from Hisar, Haryana. *Environmental monitoring and assessment*, **87**(3): 311-318.

Kumari, D. and John, S. 2019. Health risk assessment of pesticide residues in fruits and vegetables from farms and markets of Western Indian Himalayan region. *Chemosphere*, **224:** 162-167.

Kumari, D. and John, S. 2018. Safety and occupational health hazards of agricultural workers handling pesticides: A case study. In *Advances in Health and Environment Safety* (pp. 75-82). Springer, Singapore.

Lacina, O., Zachariasova, M., Urbanova, J., Vaclavikova, M., Cajka, T. and Hajslova, J. 2012. Critical assessment of extraction methods for the simultaneous determination of pesticide residues and mycotoxins in fruits, cereals, spices, and oil seeds employing ultra-high performance liquid chromatography-tandem mass spectrometry. *Journal of Chromatography A*, **1262**: 8-18.

Lichter, A., Dvir, O., Rot, I., Akerman, M., Regev, R., Wiesblum, A. and Fuchs, Y. 2000. Hot water brushing: an alternative method to SO2 fumigation for color retention of litchi fruits. *Postharvest Biology and Technology*, **18**(3): 235-244.

Liu, J., Sui, G., He, Y., Liu, D., Yan, J., Liu, S. and Qin, W. 2014. Prolonging Storage Time of Baby Ginger by Using a Sand-Based Storage Medium and Essential Oil Treatment. *Journal of food science*, **79**(4): M593-M599.

Liu, Y.. B. 2014. Nitric oxide as a new fumigant for post harvest pest control on fresh commodities. In *XXIX International Horticultural Congress on Horticulture: Sustaining Lives, Livelihoods, and Landscapes (IHC2014):* **1105** (pp. 321-328).

Liu, Y. B. and Yang, X. I. A. N. G. B. I. N. G. 2016. Prospect of nitric oxide as a new fumigant for postharvest pest control. In *Proc. 10th Intl. Conf. Controlled Atmosphere and Fumigation in Stored Products (CAF2016), CAF Permanent Committee Secretariat, Winnipeg, MB, Canada* (pp. 161-166).

Lozowicka, B. 2015. Health risk for children and adults consuming apples with pesticide residue. *Science of the Total Environment*, **502**: 184-198.

Margni, M., Rossier, D., Crettaz, P. and Jolliet, O. 2002. Life cycle impact assessment of pesticides on human health and ecosystems. *Agriculture, ecosystems and environment*, **93**(1-3): 379-392.

Mewa-Ngongang, M., Du Plessis, H. W., Ntwampe, S. K. O., Chidi, B. S., Hutchinson, U. F., Mekuto, L. and Jolly, N. P. 2018. Fungistatic and Fungicidal Properties of Candida pyralidae Y1117, Pichia kluyveri Y1125 and Pichia kluyveri Y1164 on the Biocontrol of Botrytis Cinereal. In *Proceedings of the 10th International Conference on Advances in Science, Engineering, Technology and Healthcare (ASETH-18), Cape Town, South Africa* (pp. 19-20).

Miao, G., Han, J., Ye, T., Chen, Z. and Zhang, K. 2018. Efficiency and Safety Assurance of Six Fungicides Applied on Postharvest Cabbages Stored in a Natural Environment. *Journal of agricultural and food chemistry*, **66**(41): 10864-10870.

Mohamed, A. O., Mater, A. A., Hammad, A. M., Ishag, A. E., Abdelbagi, A. O., Eldein, A. M. and Gader, A. A. 2019. Knowledge, attitudes and practices of pesticide's sprayers towards pesticides use and handling in greenhouse farms, Sudan. *International Journal of Management and Commerce Innovation*, **6**(2): 840-50.

Mostafalou S and Abdollahi M. 2013. Pesticides and human chronic diseases: evidences, mechanisms, and perspectives. *Toxicology and Applied Pharmacology,* **268** (2): 157-177.

Narváez, A., Rodríguez-Carrasco, Y., Izzo, L., Castaldo, L. and Ritieni, A. 2020. Target quantification and semi-target screening of undesirable substances in pear juices using ultra-high-performance liquid chromatography-quadrupole orbitrap mass spectrometry. *Foods*, **9**(7): 841.

Oh, S. and Liu, Y. B. 2020. Effectiveness of nitrogen dioxide fumigation for microbial control on stored almonds. *Journal of food protection*, **83**(4): 599-604.

Opit, G. P., Phillips, T. W., Aikins, M. J.. and Hasan, M. M. 2012. Phosphine resistance in Tribolium castaneum and Rhyzopertha dominica from stored wheat in Oklahoma. *Journal of Economic Entomology*, **105**(4): 1107-1114.

Petersen, A., Jensen, B. H., Andersen, J. H., Poulsen, M. E., Christensen, T. and Nielsen, E. 2013. *Pesticide residues: results from the period 2004-2011*. National Food Institute, Technical University of Denmark.

Russo, P.; Englezos, V.; Capozzi, V.; Pollon, M.; Río Segade, S.; Rantsiou, K.; Spano, G. and Cocolin, L. 2020. Effect of mixed fermentations with *Starmerella bacillaris* and *Saccharomyces cerevisiae* on management of malolactic fermentation. *Food Research International*, **134**: 109246.

Samsidar, A., Siddiquee, S. and Shaarani, S. M. 2018. A review of extraction, analytical and advanced methods for determination of pesticides in environment and foodstuffs. *Trends in Food Science and Technology*, **71**: 188-201.

Seo, S. T., Balock, J. W., Burditt Jr, A. K.. and Ohinata, K. 1970. Residues of ethylene dibromide, methyl bromide, and ethylene chlorobromide resulting from fumigation of fruits and vegetables infested with fruit flies. *Journal of economic entomology*, **63**(4): 1093-1097.

Shenker, M., Harush, D., Ben-Ari, J. and Chefetz, B. 2011. Uptake of carbamazepine by cucumber plants–a case study related to irrigation with reclaimed wastewater. *Chemosphere*, **82**(6): 905-910.

Shi, K., Liu, Z., Wang, J., Zhu, S. and Huang, D. 2019. Nitric oxide modulates sugar metabolism and maintains the quality of red raspberry during storage. *Scientia Horticulturae*, **256:** 108611.

Shuang, Y., Zhang, T. and Li, L. 2020. Preparation of a stilbene diamido-bridged bis (β-cyclodextrin)-bonded chiral stationary phase for enantioseparations of drugs and pesticides by high performance liquid chromatography. *Journal of Chromatography A*, **1614**: 460702.

Si, W. S., Wang, S. Y., Zhang, Y. D., Kong, C. and Bai, B. 2021. Pesticides and risk assessment in Shanghai fruit and raw eaten vegetables. *Food Additives and Contaminants:* **Part B**: 1-11.

Sinha, S. N., Rao, M. V. V. and Vasudev, K. 2012. Distribution of pesticides in different commonly used vegetables from Hyderabad, India. *Food Research International*, **45**(1): 161- 169.

Slowik-Borowiec, M., Szpyrka, E., Rupar, J., Podbielska, M. and Matyaszek, A. 2016. Occurrence of pesticide residues in fruiting vegetables from production farms in south-eastern region of Poland. *Roczniki Państwowego Zakładu Higieny*, **67**(4).

Stefanelli, P., Santilio, A., Cataldi, L. and Dommarco, R. 2009. Multiresidue analysis of organochlorine and pyrethroid pesticides in ground beef meat by gas chromatography-mass spectrometry. *Journal of Environmental Science and*

Health Part B, **44**(4): 350-356.

Sun, J., Jiang, X., Chen, Y., Lin, M., Tang, J., Lin, Q. and Lin, H. 2022. Recent trends and applications of electrolyzed oxidizing water in fresh foodstuff preservation and safety control. *Food Chemistry*, **369:** 130873.

Swarnam, T. P., and Velmurugan, A. 2013. Pesticide residues in vegetable samples from the Andaman Islands, India. *Environmental monitoring and assessment*, **185(**7): 6119-6127.

Tang, Y., Xu, K., Zhao, B., Zhang, M., Gong, C., Wan, H. and Yang, Z. 2021. A novel electronic nose for the detection and classification of pesticide residue on apples. *RSC Advances*, **11**(34): 20874-20883.

Tzatzarakis, M., Kokkinakis, M., Renieri, E., Goumenou, M., Kavvalakis, M., Vakonaki, E.and Tsatsakis, A. 2020. Multiresidue analysis of insecticides and fungicides in apples from the Greek market. Applying an alternative approach for risk assessment. *Food and Chemical Toxicology*, **140:** 111262.

Umsza-Guez, M. A., Silva-Beltrán, N. P., Machado, B. A. S. and Balderrama-Carmona, A. P. 2021. Herbicide determination in Brazilian propolis using high-pressure liquid chromatography. *International journal of environmental health research*, **31**(5): 507-517.

United Nations Environment Programme. Ozone Secretariat. 2006. *Handbook for the Montreal protocol on substances that deplete the ozone layer*. UNEP/Earthprint.

Visse-Mansiaux, M., Tallant, M., Brostaux, Y., Delaplace, P., Vanderschuren, H. and Dupuis, B. 2021. Assessment of pre-and postharvest anti-sprouting treatments to replace CIPC for potato storage. *Postharvest Biology and Technology*, **178**: 111540.

Ward, N., Clark, J., Lowe, P. and Seymour, S. 1993. Water pollution from agricultural pesticides. *Centre for Rural Economy Research Report. Newcastle upon Tyne: Centre for Rural Economy*.

Wesseling, C., Keifer, M., Ahlbom, A., McConnell, R., Moon, J. D., Rosenstock, L. and Hogstedt, C. 2002. Long-term neurobehavioral effects of mild poisonings with organophosphate and n-methyl carbamate pesticides among banana workers. *International Journal of Occupational and Environmental Health*, **8**(1): 27-34.

Wu, Y., An, Q., Li, D., Wu, J. and Pan, C. 2019. Comparison of different home/ commercial washing strategies for ten typical pesticide residue removal effects in kumquat, spinach and cucumber. *International journal of environmental research and public health*, **16**(3): 472.

Xiao, O., Li, M., Chen, J., Li, R., Quan, R., Zhang, Z. and Dai, X. 2020. Influence of Triazole Pesticides on Wine Flavor and Quality Based on Multidimensional Analysis Technology. *Molecules*, **25**(23): 5596.

Yang, J., Song, L., Pan, C., Han, Y. and Kang, L. 2020. Removal of ten pesticide residues on/in kumquat by washing with alkaline electrolysed water. *International Journal of Environmental Analytical Chemistry*, 1-14.

Yang, X., and Liu, Y. B. 2017. Residual analysis of nitric oxide fumigation on fresh fruit and vegetables. *Postharvest Biology and Technology*, **132**: 105-108.

Yang, X. and Liu, Y. B. 2018. Nitric oxide fumigation for control of spotted wing Drosophila (Diptera: Drosophilidae) in strawberries. *Journal of economic entomology*, **111**(3): 1180-1184.

Yang, X., Liu, Y. B., Simmons, G., Light, D. and Haff, R. 2021. Nitric oxide fumigation for control of navel orangeworm, Amyelois transitella, on walnut. *Journal of Applied Entomology*, **145**(3): 270-276.

Yu, Y., Qu, Y., Zhang, M., Guo, X. and Zhang, H. 2020. Fluorescence detection of paclobutrazol pesticide residues in apple juice. *Optik*, **224**: 165542.

Zhang, Q., Xu, G., Guo, N., Wang, T., Song, P. and Xia, L. 2021. In-Situ Synthesis of Methyl Cellulose Film Decorated with Silver Nanoparticles as a Flexible Surface-Enhanced Raman Substrate for the Rapid Detection of Pesticide Residues in Fruits and Vegetables. *Materials*, **14**(19): 5750.

Zhang, W., Cao, J., Fan, X. and Jiang, W. 2020. Applications of nitric oxide and melatonin in improving postharvest fruit quality and the separate and crosstalk biochemical mechanisms. *Trends in Food Science and Technology*, **99:** 531-541.

Chapter - 14

Management of Pesticide Residues

C.G. Sawant and Ajaykumara K.M.

Introduction

Pesticide toxicity in humans shows differences when occurring through air and food contamination routes. The main scientific information and control efforts are obtained and performed regarding pesticide residue limits in food established by registration procedures. In general, pesticide effects are displayed as chronic disease, in particular regarding endocrine disruptors, in which pesticides are gradually bioaccumulated up to high residue concentrations through daily intake. Pesticide air pollution is the main source of contamination, resulting in acute toxicity in people that work directly with pesticide pulverization.

Pesticide Residue Management at Farm Level

The highest risk is towards small farmers that use knapsacks and move in the pesticide cloud, protected or not by individual protection equipment (PPE). Green barriers can trap drifting pesticide droplets and, in some cases, also include volatilized air residues. These barriers can comprise forest strips or hedgerows, and can be planted in the vicinity of farms, margin of roads and mainly urban areas. The protection of surface water is established by law by riparian forest protection or reforestation. Plant barriers cannot be used as food due to high pesticide accumulation, due to exposure to manifold pulverization. These barriers are more efficient when they are as wide as possible. For large farms, it is best to use forest strips at least 10 meter wide, but in smaller farms this approach demands the occupation of significant areas, so it is therefore advisable to use 1 or 2 meter wide hedgerows, with twice the height of the cultivated plants, or at least 1 meter higher (Langenbach and Caldas, 2018).

Pesticide residue management by safe handling practices

The safety handling practices of pesticide are as follows. Read the pesticide labels properly for safety instructions and directions of use. Store the pesticides at a place that can be locked and is not accessible to unauthorized people or children. Left over pesticides should be disposed off properly by pouring it into trenches in the ground or a pit latrine. It should not be disposed just near source of drinking water or washing, fish ponds or rivers. Containers of pesticide after use should be rinsed, completely filled with water, and not allowed to stand for 24 hours. They should then be emptied, and the process repeated twice (FSSAI, 2020). Do not eat, drink or smoke while handling or using pesticides. Take a shower or bath after every operation. Gloves should be worn when handling pesticide concentrate and preparing mixtures or spray solutions. Safe use practices to reduce/eliminate pesticide residues during transport, storage and handling (Anon. 2020).

Good agriculture practices : A tool of pesticide residues management

Good agriculture practices (GAP) in pesticide application can reduce the risk of pesticide pollutions and contaminations to users. It is nothing but a nationally authorized safe usage of pesticides and necessary as strategiy for effective and reliable pest control under field conditions. It encompasses a range of levels of pesticide applications up to the highest authorized use, applied in a such manner which leaves a residue in smallest practicable amount. However, farmers require knowledge on the correct dosage, appropriate methods of application and the recommended interval between pesticide treatment and harvesting. In most under developed and developing countries, farmers are unware and have less knowledge about pesticides and its safety usage. Farmers also use pesticide indiscrimatly and unwisely and poorly disposed empty its containers. Poor or less knowledge in most cases is attributed to lack of training and monitoring in pesticide use and handling. farmers inability to adhere to stipulated instructions leads to pesticide exposure not only to themselves but to the general public and the environment (Mwanja *et al.*, 2017).

Adopt the Good Agricultural Practices (Q-GAP) in crop protection. Q-GAP guidelines emphasize pre-farm gate farm practices. These guidelines are a set of standard that requires farmers to record their use of agrochemicals and to use them in a proper and as per recommonded way. Prescribed pre-harvest spraying interval i.e., number of days before the harvest during which spraying of pesticides is not allowed. Integrated pest management (IPM) is as an integral part of GAP by concentrating on non chemical methods such as insect traps, bio-pesticides, or mechanical control methods. The use of pesticides such as extremely hazardous, highly hazardous, and moderately hazardous in terms of the total quantity of active ingredients should be minimized under the Q-GAP standard. Needs to pay more attention towards on-farm practices and ensure that farmers have suitable alternatives to chemical pesticides when controling pests. Standardized IPM practices for each crop and providing training to farmers on how to use those. Monitoring of pesticide residues on fruits and vegetables suggests that, the government is more concerned with limiting the consequences of pesticide overuse and misuse, presumably to avoid negative repercussions on food export opportunities (Schreinemachers *et al.*, 2012).

The Pre Harvest Strategies for Pesticide Residue Reduction

Pesticides play a vital as well as very sensitive role in production of food as they are mostly applied to protect crops from insect, diseases, weeds, etc. but besides this they have negative impacts on different ecosystems in the environment and human health too. While global pesticide usage has been increasing up to 3.5 billion kg active ingredients per year, a significant portion applied has proved to be excessive, uneconomic or unnecessary both in industrialized and developing countries (Pierpaolobacciu, 2017). Following are the seven strategies given by Pierpaolobacciu, 2017.

1. Agronomical practices

Suitable agronomical practices are essential to achieve healthy crops life and to prevent build-up of pest, disease and weed pressure over them healthy crops. The following practices are of particular important.

- Management of plant nutrition and soil fertility.
- Crop rotation.
- Appropriate irrigation management.
- Appropriate timing of sowing or planting and of intercultural operations in order to reduce pest attack.
- Timely shallow tillage reduces weed populations and at the same time improves nutrient supply to the crop.
- Precision farming like spraying of hot-spots and weeding with optical detectors.
- Intercropping (when it is possible) and the use of variety mixtures limits the spread of pests and diseases and provides food and shelter for natural enemies of pests.

2. Host plant resistance

Crops and crop varieties differ in their susceptibility to pests and diseases and in their ability to compete with weeds. Growing crops suitable for local conditions and selecting appropriate crop varieties is therefore fundamental to a prevent pest attack. The use of resistant varieties together with rotations of non-susceptible crops can substantially limit pest build-up within a field. Use of resistant/tolerant cultivars based on antixenosis or antibiosis mechanisms can reduce the pest load on crop and ultimatle pesticide residues in crops.

3. Bio-control agents and micorbial pesticides

Bio-control makes use of entomopathogens (bacteria, fungi, and viruses), insect predators or parasitoids, pheromones and insect traps to keep pest populations low. The complete eradication of a pest, which results from the use of synthetic pesticides, would reduce the food supply of the pest's natural enemies, undermining a key element in system resilience. The aim, therefore, should be to manage insect pest populations rather than to total eradication to the point where natural predation operates in a balanced way and crop losses to pests are kept to an acceptable minimum.

4. Integrated pest management (IPM)

IPM is an ecosystem approach that does not seek to total eradicate pests but rather to manage them. It is founded on the idea that the first and most fundamental line of defense against pests and diseases in agriculture is a healthy agro-ecosystem, in which the biological processes that underpin production are protected, encouraged and enhanced. In a true IPM strong focus will be given to pest prevention by applying good agronomic practices and using resistant varieties, pest identification and monitoring and biological pest control. As soon as the economic threshold is achieved the point at which the cost of pesticide use pays off (cost of expected loss in harvest exceeds the cost of treatment) chemical pest control becomes profitable. The last step includes learning and adapting from IPM for the next crop season.

5. Agro-ecology

Agroecology is a discipline that defines, classifies and studies agricultural systems from an ecological and socio-economic perspective, and applies ecological concepts and principles to the design and management of sustainable agroecosystems. It is an integrative way of farming that focuses on working with and understanding the interactions between plants, animals, humans and the environment. In Agroecology pest control seeks to reinforce interactions of pests and natural enemies with the aim to maintain a natural balance in the ecosystem. While there is no consent on what techniques and inputs are compatible with agroecology the common denominator is to make use of biodiversity-based ecological processes to optimize agricultural production systems. Ecological engineering in other terms called as 'Habitat Manipulation' is mainly focuses on reducing the mortality of natural enemies, providing the supplementary resources and manipulating host plant attributes for the benefit of natural biocontrol agents. The ecological engineering for pest management has recently emerged as a new paradigm to enhance the natural enemies of pests in an agro ecosystem and is being considered an important strategy for promoting Bio intensive Integrated Pest Management (BIPM).

6. Organic agriculture

Organic agriculture is a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic standards strictly prohibit any use of synthetic pesticides. Crop protection in organic agriculture builds on good agronomic practices such as crop rotation and intercropping, the use of organic manures, resistant varieties and bio-control to prevent that pest, diseases and weeds cause significant damage. Practice of natural farming where animal urine and native plants based extractions will be used for eco-friendly pest management. Development of proper market chain and reasonable prices for organically produced fruits and vegetables encourages the farmers to adapt organic crop protection thereby helps to minimize pesticide residue problems.

7. Use of less hazardous pesticides

There are various systems to classify pesticides as per their toxicity for humans and the environment. Phasing out the use of highly hazardous pesticides and replacing them with less hazardous ones is therefore the most obvious way to reduce the negative side-effects of pesticides. This approach needs to be combined with safe handling of pesticides so that their impact on people and the environment is minimized. The use of protective gear and the observation of waiting periods before harvest are the most important measures in this regard (Anon. 2016).

Following are the some other strategies suggested to avoid pesticide residues in field.

8. Avoid calendar spraying

Calendar spraying is nothing but when pesticides are applied on a schedule without considering the actual presence or extent of pests and diseases on the crop. This leads to accumulation of pesticide residues in crops. This practice can also result in pesticides being applied when they are not needed, can increase pest and disease resistance and be a waste of time and money (Sophie *et al*.,2006).

9. Monitoring of pests and diseases

Regularly monitoring of crops for pests and diseases by magnifying glass or hand lens for the presence of pests and disease such as thrips, mites, etc. Sticky traps can also be used to check for the presence of aphids, jassids, thrips and whiteflies. Regular monitoring can ensures problems are found early, making control easier and saving you time and money. Additionally, monitoring records will allow you to evaluate the effectiveness of control methods and identify the time of the year for particular pest and disease issues (Sophie *et al*.,2006).

10. Prevention of spray drift

Preventing spray drift in field and different crops is also important methods in reducing the risk of pesticide residues. Make sure that there is no strong wind in fields while spraying. Do not spray against wind direction. Never enter in the treated field immediate after spray without bearing protective clothings.

The Post Harvest Strategies for Pesticide Residue Reduction

After harvest, fruits and vegetables are subjected to various handling and processing operations both in the kitchen or at large scale industry level, involving a simple washing to more multi-step and complex processing which aims to decontaminate the produce, extend their shelf-life, add variety, increase palatability and nutrient availability and to generate income. The various culinary methods applied usually reduce residue levels because of washing or cleaning with salt solution, tamarind water and vinegar, peeling, blanching, fermentation, juicing, cooking, milling, baking, pasteurization, canning, etc. The various preparatory or culinary processes and post-harvest handling for fruits and vegetables have been elaborated under the following heads.

1. Washing with plane water

Fruits and vegetables are invariably washed before consumption. Vegetables are often peeled off and cooked before eating. Various decontamination processes to dislodge pesticide like washing the fruits and vegetables with water were reported with varying degrees depending on the types of the fruit and vegetables, chemical nature of the pesticide, and environmental conditions. Effectiveness of washing out pesticide residues depends on several factors: the location of residues, the "age" of residues (as some residues tend to move into deeper layers of commodities with time), the solubility of pesticides and the type of wash. Overall, however, washing of food commodities prior to eating and/ or further processing is a highly recommended procedure.

2. Washing with solutions

Although washing with tap water has proved to be a significantly effective, simple, common and convenient method for removing pesticide contaminants from food surfaces, it has been shown that washing with dilute salt or chemical solutions can often be even more effective to this cause. Washing with 2 to 10 % concentration of dilute sodium chloride, sodium carbonate, sodium bicarbonate, vinegar, acetic acid, citric acid, ascorbic acid, ethanol, turmeric and tamrind solution, chlorinated and ozonated water, etc., were proved convenient methods to lower the load of contaminants from food surfaces particularly fruits and vegetables. This method could be equally effective for reducing the conventional as well as newer pesticide residue from other commodities too. This procedure is recommended as being practical for household use.

3. Peeling

Peeling is an important step in the processing of most fruits and vegetables. Whether it is chemical, mechanical, steam or freeze peeling, this method can achieve significant or virtually total removal of pesticide residues from many commodities, depending on their constitution, the chemical nature of the pesticides, and environmental conditions. Chemical peeling (mostly lye peeling), mechanical peeling (mainly abrasion peeling), steam peeling and freeze peeling are conventional methods for peeling in the processing of fruits and vegetables (Toker and Bayindirli, 2003).

A majority of the pesticides applied directly to crops undergo very limited movement or penetration of the outer surface of fruits and vegetables. It is therefore follows that residues of pesticides are confined to the outer surfaces where they are amenable to removal in peeling, hulling or trimming operations. Peeling fresh fruits and vegetables can significantly achieves virtually complete removal of residues. Both systemic and contact pesticides that appear on the surface of the fruits and vegetables can be removed by peeling. Steps such as concentration, dehydration and extraction from the raw product can further reduce pesticide residues in the end product. The net influence of processing almost always results in minimal residues in processed food.

4. Peeling, hulling and trimming

A majority of the insecticides or fungicides applied directly to crops undergo very limited movement or penetration of the cuticle. It therefore follows that residues of these materials are confined to the outer surfaces where they are amenable to removal in peeling, hulling or trimming operations.

5. Comminution

Disturbance of tissues in chopping, blending etc. leads to release of enzymes and acids which may increase the rate of hydrolytic and other degradative processes on residues that were previously isolated by cuticular layers. For example, fine chopping of crop samples leads to rapid degradation of EBDC fungicide residues (Howard and Yip, 1971). However most pesticides are relatively stable in acidic tissue homogenates for the moderate periods of time involved in food preparation.

6. Drying

Drying is one of the common and oldest method of preserving foods including fruits, vegetables, cereals, pulses, meat, etc., Food commodities can be dried in several ways, for example, by means of sun or in an oven or a food dryer can also be used. As compared with other methods, drying is quite simple and easy. Drying helps in degradation of thermosensitive pesticides upon exposure.

7. Fermentation

It is a simple process during which the enzymes hydrolyze most of the proteins to amino acids and low molecular weight peptides; starch is partially converted to simple sugars which are fermented primarily to lactic acid, alcohol and carbon dioxide (Pardez-Lopez *et al*., 1991). Fermentation process is mainily employed in juice, meat and milk industry to prepare various products. Fermentation has been studied also for reduction in pesticide residues.

8. Freezing

Freezing food is a common method of food preservation which delay both food decay and most chemical reactions. A study conducted by Abou-Arab, (1999) found that when tomatoes contaminated at level of 1 ppm were freezed the reduction of residues were 5.28 %, 7.02 %, 5.74 %, 28.5 %, 26.6 % and 26.2 % after six days and 10.6 %, 16.3 %, 13.0 %, 32.6 %, 28.2 % and 31.4 % loss after 12 days with HCB, lindine, p,p DDT, dimethoate, profenofos and pirimiphos-methyl, respectively.

9. Infusion

Tea and coffee are popular beverages throughout the world. A cup of tea that cheers can also be an important route of human exposure to pesticide residues. It is therefore important to evaluate the percent transfer of pesticide residue from dried (made) tea to tea infusion, as tea is subjected to an infusion process prior to human consumption (Jaggi *et al*., 2000).

10. Juicing

In Commercial juicing process the whole fruit is used. The residue levels in juices obtained from fruit will depend on the partitioning properties of the pesticide between the fruit skins or pulp and the actuall juice which also contain some solids materials. The pulp which often includes the skin, retain a substantial proportion of lipophilic residues. Thus moderately to highly lipophilic pesticides such as parathion, folpet, captan and synthetic pyrethroids are poorly transferred into juices and the residues are further reduced by clarification operation such as centrifugation or filtering (Holland *et al*., 1994).

11. Malting

Malting is a two phase process which includes germination and the kiln-drying process. The stages of malting are steeping, germination and kilning (drying and curing) contributed to loss of pesticide residues. It is mostly applied to cereal grains in the preparation of bears, wines, rum, whisky, etc. in liquor industry. The fate of pesticides was determined from barley to malt. The residues amount remaining after malting process is ranged from 13–51 % for fenitrothion and nuarimol. Steeping was the most important stage in removal of residues (52 %) followed by germination (25 %) and kilning (23 %) (Navarro *et al*., 2007). Hence, most of the loss of residues during malting seems to be on account of high dilution with water (Holland *et al*., 1994).

12. Milling

Milling is a process in which cereal grains such as oats, wheat, rice, sorghum, bajra, barley, and corn are dehulled and grounded into smaller pieces or flours in order to improve palatability, reduce cooking time, and create food products. Most of pesticidal residues are present in the outer portions of the grain, and consequently 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 (Holland *et al*., 1994). The milling of grains substantially removes the residues.

13. Parboiling

Parboiling means precooking of rice within the husk. Parboiling involves first hydrating paddy followed by heating to cook the rice and finally drying of the rice. The percentage of reduction due to parboiling of the residues of pesticides used in the study was 68 % for Lebaycid, 51 % for Dursban and 49 % for Ekalux (Krishnamurthy and Sreeramulu, 1982).

14. Thermal processing

Application of heat to food commodities is commonly done through ordinary cooking, pressure cooking, microwave cooking, frying, sterilization and canning.

a. Canning

This is a commercial process in its various forms combines elements of washing, peeling, juicing, cooking and concentration. Canning can be a safe and economical way to preserve quality food at home. Generally it is a method of food preservation in which food is processed, hermetically sealed and then sterilized by heat in an airtight container (jars like Mason jars, and steel and tin cans). During the canning process one or more steps may be omitted such as peeling, cooking etc,. Heating is one of the most important setps in canning to sterilize the containers before or after the sealing. During the sterilization, heat is applied at specific rate and time. Thermo degradable pesticides are easily removed by this process. Processing of whole tomatoes with vinclozolin residues of 0.73 mg/kg gave residues in canned juice, puree and ketchup of 0.18, 0.73 and 0.22 mg/kg, respectively (FAO/WHO, 1986).

b. Cooking

Cooking is the daily process of preparing food by the application of heat till softing the tissues of fruits and vegetables. It encompasses a vast range of methods depending on the customs and traditions, availability and the affordability of the resources. Most pesticides are complex organic molecules and these tend not to be very heat stable. But reliably breaking down all pesticide molecules would likely require prolonged exposure to temperatures well over 100^{o}C, so you can't rely on ordinary cooking to remove all traces. Cooking includes open pan boiling and steam cooking. The time for cooking, temperature given, moisture loss during cooking and whether the cooking is in open or closed pan are important to the quantitative effects on residue levels. Rates of degradation and volatilisation of residues are increased by the heat involved in cooking. Literature is replete with work on effect of cooking on pesticide residues dissipation. For example, potato and cabbage mash fortified with dimethoate at 2 ppm level on 30 min boiling gave percentage hydrolysis in range of 37– 53 % and 56–86 %, respectively (Askew *et al.*, 1968). Bitter gourds treated with endosulfan sprays received initial deposits of 18.97 ppm and 26.01 ppm which were respectively removed to extent of 63.82 % and 25.38 % by 10 min of open cooking and 67.85 % and 36.94 % by 10 min of steam cooking (Nath and Agnihotri, 1984).

c. Washing and cooking

Washing and cooking also a day ordinary process in kitchen. According to findings of Thanki *et al*., (2012) washing, boiling and cooking processes minimized the pesticide residues of nine pesticides in the range of 3.32-70.0, 21.08-70.67 and 31.63- 85.30 % respectively. It was also found that washing and cooking processes minimized the cypermethrin, captafol and parathion residues in the range of 1.74-64.78 % and 38.40 - 90.15 % respectively (Thanki *et al*., 2012). Apples followed by cooking (including processing apple to sauce) reduced the amount of residue by 98 %. The total amount of residue on the control unwashed fruit was determined to be 0.67 ppm (Ong *et al*., 1996). Washing and steaming of chickpea grains completely removed the Deltamethrin residues from an initial level of residues of 0.051 ppm (Lal and Dikshit, 2001).

The residue of iprodione in prune at harvest time was 0.68 ppm which became 0.30 ppm after washing with water for 5 min, oven drying and rehydration (Cabras *et al*., 1998).

15. Washing and peeling

Kong and co-workers in 2012 reported that, washing and peeling of tomato reduces the residues of difenoconazole by 99 %. Reduction of lindane levels in fortified tomatoes ranged from 15 % (washing with tap water) to 82 % (after peeling) as reported by Abou-Arab (1999). Reduction of residues of chlorpyriphos and cypermethrin in Asparagus was 73 to 75 % after washing and peeling as reported by Chavarri *et al*., (2005). Captan residues in apples washed with de-ionized water for 10–15 seconds with continuous hand rubbing were 50% lower than in those apples that received no post-harvest washing (25.8–5100 ng/g), the reduction in residues on the apples that had been washed and peeled (0.146–136 ng/g) was greatest around 98% (Rawn *et al*., 2008).

16. Washing, peeling and juicing

This processing method mostly followed in fruits and vegetables such as lemon, pomegranate, banana, mango, cucumber, tomato, etc. in order to remove outer surface to prepare juices and its byproducts or for its cooking. However, the residues existed in the outer surface of the fruits and vegetables but not in the juice till juicing. So it is necessary to peel the fruits and vegetables before further process.

17. Wine making

During the manufacture of wine in addition to the transfer of residues from the grapes into the must, stability of residues to the fermentation and fining processes are important factors. Fermentation on the skins as carried out in red wine production is likely to lead to higher residues in raw wine. Residues in must may be absorbed to the solids produced during fermentation and thus be lost in the fining processes. However, a range of pesticides with suitable solubilities and stabilities can give rise to residues in wine (Holland *et al*., 1994).

References

Abou-Arab, A. A. K. 1999. Behavior of pesticides in tomatoes during commercial and home preparation. *Food Chemistry*, 65, 509–514.

Anomymous, 2016. A scheme and training manual on good agricultural practices for fruits and vegetables. Volume 1, The scheme - standard and implementation infrastructure. FAO, Bangkok.

Anonymous, 2020. Pesticides: Food safety concerns, Precautions and Safety measures.

Askew, J., Mitchell, T. H., Thomson, J., and Wheals, B. B. 1968. The gas chromatographic examination of organophosphorous pesticides. *Journal of Chromatography*, 32, 417–418.

Cabras, P., Angioni, A., Garau, V. L., Pirisi, F. M., Brandolini, V. and Cabitza, F. 1998. Pesticide residues in prune processing. *Journal of Agricultural and Food Chemistry,* 46, 3772–3774.

Chavarri, M.J., Herrera, A., and Arino, A., 2005. The decrease in pesticides in fruit and vegetables during commercial processing. *Int. J. Food Sci. Technol*., 40: 205-211.

FAO/WHO. 1986. Pestic residues in food – 1986. Report joint meeting on pesticide residues (JMPR), FAO, Rome, *Plant production and protection paper* 77.

FSSAI. 2020. Guidance Note No. 13/2020.

Holland, P. T., Hamilton, D., Ohlin, B. and Skidmore, M. W. 1994. Effects of storage and processing on pesticide residues in plant products. IUPAC Reports on Pesticides (31). *Pure and Applied Chemistry*, 66(2), 335–356.

Howard, S. and G. Yip. 1971. Effect of food processing on pesticide residues. *J. Assoc. Offic. Anal.*. 3, 1371-1372.

Jaggi, S., Sood, C., Kumar, V., Ravindranath, S. D., and Shanker, A. 2000. Loss of quinalphos during tea processing. *Pestology,* 24(12), 42–46.

Kong, Z., Dong, F., Xu, J., Liu, X., Zhang, C., Li, J., Li, Y., Chen, X., Shan, W. and Zheng, Y., 2012. Determination of difenoconazole residue in tomato during home canning by UPLC-MS/MS. *Food Control*, 23: 542-546.

Krishnamurthy, V. V. and Sreeramulu, U. S. 1982. Studies on rice bran and rice bran oil. VI. Pesticides accumulation in the rice bran. *Madras Agricultural Journal*, 69(12), 820–821.

Lal, A. K. and Dikshit, A. K. 2001. The protection of chickpea (Cicer arietinum L.) during storage using deltamethrin on sacks. *Pesticide Research Journal,* 13(1), 27–31.

Langenbach, T. and Caldas, L. Q. 2018. Strategies for reducing airborne pesticides under tropical Conditions. Ambio, 47:574–584.

Mwanja, M., Jacobs, C., Mbewe, A. R. and Munyinda, N. S. 2017. Assessment of pesticide residue levels among locally produced fruits and vegetables in Monze district, Zambia. International Journal of Food Contamination, 4(11).

Nath, G. and Agnihotri, S. 1984. Removal of endosulfan from bitter gourds by home processings. *Pesticides,* 18(8), 13–15.

Navarro, S., Perez, G., Navarro, G. and Vela, N. 2007. Decline of pesticide residues from barley to malt. *Food Additives and Contaminants*, 24(8), 851–859.

Ong, K. C., Cash, J. N., Zabik, M. J., Saddiq, M. and Jones, A. L. 1996. Chlorine and ozone washes for pesticide removal from apples and processed apple sauce. *Food Chemistry*, 55(2), 153–160.

Pardez-Lopez, O., Gonzales-Casteneda, J. and Carabenz-Trejo, A. J. 1991. Influence of solid substrate fermentation on the chemical composition. *Journal of Fermentation and Bioengineering*, 71, 58–62.

Pierpaolobacciu, 2017. http://www.casaqa.com/2017/11/01/seven-strategies-to-reduce-pesticide-usage.

Rawn, D. F. K., Quade, S. C., Sun, W., Fouguet, A., Belanger, A., and Smith, M. 2008. Captan residue reduction in apples as a result of rinsing and peeling. *Food Chemistry*, 109, 790–796.

Schreinemachers, P., Schad, I., Tipraqsa, P., Williams, P. M., Neef, A., Riwthong, S., Sangchan, W. and Grovermann, C. 2012. Can public GAP standards reduce agricultural pesticide use ? The case of fruit and vegetable farming in northern Thailand. Agric Hum Values, 29:519–529.

Sophie, Parks., Sandra, Hardy. and Jeremy, Badgery, Parker. 2016. Minimising pesticide residues in greenhouse and hydroponic crops. *Information on pesticide issues*, No.19, pp.1-3.

Thanki, N., Joshi, P. and Joshi, H., 2012. Effect of household processing on reduction of pesticide residues in cauliflower (B*rassica oleraceae var. botrytis*). *Euro. J. Exp. Bio*., 2: 1639- 1645.

Toker, I. and Bayindirli, A. 2003. Enzymatic peeling of apricots, nectarines and peaches. *Lebensmittel-Wissenschaftund-Technologie*, 36(2), 215–221.

Chapter - 15

Alternatives to Pesticides

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Introduction

Pesticides are extensively used in agriculture to control insect pests, diseases, and weeds. The control of these serves to increase crop yield and decrease manual labor. However, most chemical pesticides impart long-time hazards to the environment and human health through their existence in nature and body tissues. Because of the health and environmental hazards, worldwide pest management is facing economic and ecological challenges. To overcome these challenges, regulatory actions were taken by regulatory and environmental protection agencies of different nations, and chemical pesticides are being replaced by organics, such as bio-pesticides, which pose lower or no risk to the environment and human health.

In addition to biopesticides, cultural, mechanical, physical, biological, behavioral control tactics using semiochemicals, botanicals, and transgenic are used as alternative to pesticides showing lesser toxicity to the environment and humans. To control the pests most effectively, nowadays, multiple pest control methods are adopted contemporarily. This combined pest controlling method is known as integrated pest management (IPM). IPM involves selecting, integrating, and implementing pest control primarily based on anticipated economic, ecological, and sociological consequences, including weather, disease organisms, predators, and parasites.

Why An Alternative to Chemical Pesticides

Pesticides are associated with unfavorable impacts on the health of the human and environment that have arisen from inappropriate usage and handling of pesticides by inadequately trained farm workers. For example, agricultural workers are reported to be at a greater risk of acute pesticide poisoning than 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, including eye irritation, immune system disturbances, chromosomal damage, respiratory distress, hormone disruption, male genital abnormalities, diminished intelligence, and cancer (Mokhele, 2011) Pesticides also contaminate waterways, impact non-target and beneficial organisms, and persist in the environment for years. Chemicals have also caused to bring down 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 (Agriculturist, 2018). Usage of more than recommended dosage of chemical pesticide causes resistance, resurgence, and residue problems.

Alternative tactics for pest management

i. Cultural control

ii. Mechanical control

iii. Physical control

iv. Biological control

v. Integrated pest management

I. Cultural Control

The goal of cultural management is to make the crop environment less suitable for insect pests. Many times, cultural control is used as a preventive measure. By anticipating insect problems before they occur, the control techniques reduce the pest's impact on the crop. Cultural control techniques are more successful when the target insect pests have few suitable host plants, do not disperse frequently, and have complex nutritional or environmental requirements during their life cycle.

When using cultural control methods, it is important to be aware of the field environment, production efficiency, yields, soil conservation, natural enemy habitat, crop pest, climate, and surrounding environment.

Cultural management include

1. Site selection

Sometimes, a pest can be kept away by selecting a planting site that is best suitable for the crops and the natural enemies of the insect pest but detrimental for the pest.

Factors to be considered that, history of the selected site, whether the pest has been present in the selected field in the previous season or not, its proximity to potential hibernating sites like woodlots, field borders, hedges, etc. or sites with abundant natural controls (hedges, field borders, and water sources), climate, topography, elevation, aspect, slope, weed species, micro-climate and soil conditions, etc. One important key is to avoid stressing the crop is good agronomic practices. Otherwise, when plants grow in stressed conditions, they emit signals that attract certain insect pests.

2. Planting design and management

A. Crop isolation : Crop location concerning one another and their distance of isolation can affect the crop invaded by pests. Isolation from old crops of the same group and closely related host plants that act as sources of pests is one way of reducing the chances of attack. The chance of invasion occurring will, however, increase with time. Hence, this particular practice is best appropriate for annual crops, especially climatic conditions that are not congenial. Isolation of sequentially sown crops in time to disrupt host-plant continuity and avoid easy pest dispersal.

B. Planting density and spacing : The prime objective of cultural management is to maximize yield per unit area without decreasing the quality of the crop so that yield advantages set aside pest incidence reduction. It can also be applied to lower pest population and damage. Spacing also influences the relative rate of plant growth and pest population per unit time and the pest's behavior in finding food and oviposition site. It is based on the following observations:

» Closer spacing adds to the effectiveness of natural enemies and results in effective management of pest population.

» Less density planting systems influence some pests because pests are silhouetted against the bare ground; for example, aphids are attracted to less density brassicas.

» High density crops attract some pest populations. Because of the variety of existing responses to crop spacing, extreme importance is to know the pest's biology.

Plant spacing is used to increase vigorous and healthy plants, which itself is an excellent cultural practice, e.g., good cultural protection for corn against cornstalk borer. Plant spacing that influences fast crop maturation could also provide a means of encouraging early fruit maturation and harvesting of crops of indeterminate flowering plants. This has been followed in the south region against boll weevils and pink bollworms in cotton crops.

C. Mixed cropping : This cropping pattern encourages the natural enemy population due to:

» Higher temporal and spatial distribution of pollen and nectar-rich sources.

» Increased different sources of plants covered over the ground, particularly important for diurnal enemies activity.

» Increased prey population offers alternative food resources when the pest population is scarce or at an appropriate period in the predator's life cycle. It also affects the insect pests' ability to search host plants by conferring associational resistance, by the non-host plant masking the odors of the host plant.

D. Time of seeding and planting

» Avoid invasion by other migrants, oviposition period of specific pests, and introduction of plant diseases by insect vectors

» To synchronize the pest attack with associated natural enemies, weather conditions that are adverse for the pest, or the abundance of alternative hosts.

» To make it feasible to destroy the crop plants before the pest reaches diapause

Time of planting can be used to allow younger plants to reach the tolerant stage before pest attack, reduce the susceptible time of the attack, reach crop maturity before pest abundance, compensate for damage and gap filling, and avoid the egg-laying period a particular insect pest.

E. Crop rotation : Crop of same plant family is followed by different plant family which is not a host crop of the pest to be managed. Almost common crop rotations involve grasses, legumes, and root crops. Crop rotations are successful against pests with a restricted host-plant range, and dispersion and pests cannot remain alive for more than one or two seasons without acceptable host crops. Pests subject to this type of management practice are poorly mobile, soil-inhabiting species with a narrow host range and one year or longer life cycle.

F. Destruction of volunteer plants : Such plants are very attractive to different insects and serve as a resource for future pest infestations. Unless volunteer plants are destroyed, they can perpetuate pest incidence by providing a food source to long-life cycled pests of preceding crops.

G. Management of alternate hosts : Several insect pests reproduce on weeds or other alternate hosts and then move to the main crops. Therefore, the need to destroy other weeds on uncultivated land to control pests such as aphids, beet leafhopper, grasshopper, and raspberry cane borer. Care should be taken not to harm nursery sites for the natural enemies of the crop pests.

H. Management of the trap crops : Trap crops are useful to divert pest incidence away from the main crop at risk by planting attractive food sources. The trap crop should be compulsorily destroyed before the pest attains the reproductive stage. This method includes the planting of a crop upon infested land so that the pest is stimulated to attack, but the crop is either harvested before pest can complete its life cycle or the pest is not provided with all requirements which are necessary for the completion of the pest's life cycle. Alternatively, the trap crops are preferentially attacked by the pest to protect the main crop.

I. Management of nursery crops : Nursery seedlings attract to the pest more than the main standing crop, but in such cases, the main aim is to provide a site for pest control and their natural controls to build up and later spread to the crop and provide effective management practice.

J. Management of surrounding environments *viz.*, field borders, hedges, water sources, and adjacent woodlots) : Such habitats can be designed and managed to provide a suitable environment for the natural enemies of pests. Repeatedly this involves providing suitable flowering crops for predators and parasitoids of pests, and care should be taken that sites must be unsuitable for overwintering pests.

3. Maintenance of site

A. Cultivation and tillage : Approach can help out in the management of soil-inhabiting pests in field conditions by

- » Exposing larvae and pupae onto the soil surface brings them to desiccation and predation, thawing, and freezing.
- » Injure the pest in the soil-inhabiting stage, ex: wireworms.
- » Destruction of the crop residues, which attracts pests that could invade new crops.
- » Deep burying of crop residues that helps to emergence from eggs or pupae is made impossible.

B. Fertilization, liming, and manuring

- Most of the phytophagous pests feeding, fecundity and longevity are influenced by plant nutrition; the common fertilizer elements N, P, and K imparts direct and indirect effects on pest population reduction. Generally, a high concentration of nitrogen helps in increasing the pest incidence, mainly sucking insect pests. Likewise, the addition of phosphorous and potassium helps to reduce the occurrence of some pests, e.g., wireworm populations more in low content phosphorous soil.
- Fertilizer application regulates fast growth and shortens all susceptible stages. It provides better tolerance and gives a chance to compensate for pest attacks. Spraying of trace mineral and plant hormones e.g., seaweed extracts, have been helps to reduce damage by some pests, certainly, sucking pests, aphids, and mites.

C. Pruning, topping, and defoliation : In the dormant phase, collection and destruction of dead, diseased, and infested wood can superiorly minimize overwintering stages of pest populations, and they spread to next year, e.g., aphids, mite eggs, scale, and fire blight infested terminals. Pruning of the water sprouts, sucker growth, and foliage in fruit trees preferred by some pests especially, aphids helps to control. And also, excessive pruning attracts certain pests such as mites, leafhoppers, and aphids.

D. Irrigation and drainage : Sometimes, insects and nematodes can be controlled by flooding the field, e.g., flooding of the infested field helps remove wireworms within three days. Certain wireworm is unable to withstand desiccation. Drying the soil is an effective control for the wireworm population.

E. Sanitation and crop residue destruction : Minimize pest incidence by removal and destruction of breeding and hibernating sites. Maintenance of field sanitation has a broad sense; most effective; one should know pest habits and careful timing. Suppression of alternate weed hosts, destruction of crop residues timely and cleaning the field bunds of alternate hosts, and demolition of shelter where pests might hide; e.g., in orchards, dropped fruits, cracks and crevices of the tree trunk are the pupation sites for codling moth, apple maggot and many other fruit pests.

F. Mulches : Plastic mulches may eliminate soil pests, and organic mulches help to permit their control by giving a suitable habitat for their natural enemies. Several fruit pests can be controlled by crop residue mulches around the base of fruit trees.

4. Harvesting procedures

A. Timing of harvesting : Early harvesting can be helpful to disrupt the life cycle of the pest in its habitat and help eliminate immature insects that are present in the foliage.

B. Strip harvesting : Crops should be harvested in alternate strips so that two different aged growths occur simultaneously in a field. When one series of strips are harvested, the other strips are about half-grown, and the field becomes a stable environment. Strip harvesting followed in alfalfa, where Lygus bugs are the problem. They travel into the younger plant strips as the older ones are harvested, instead of moving to other crops plants as they do if the whole field is cut at one time. Since natural enemies also move from strip to strip as Lygus bug moves, there is no increase in Lygus bug population in such situations. When adult Lygus move into the uncut strip, they deposit eggs in the half-grown plants, but since the hay is cut in about fifteen days, many eggs and newly emerged nymphs are destroyed at harvest.

Advantages

» Cultural methods are usually economical of all other control measures why because they only need small modifications to common production practices. However, cultural management does not even need additional labor, only careful planning. Especially for the highest acreage of lower-value crops, careful planning of cultural practices is more economical.

» Cultural management practices are dependable and are specific. Of predominant significance is that they no longer possess some of the unfavorable side effects of insecticides, namely, insecticide resistance, residues problems in food, feed crops, and the environment, and adverse effect on non-target organisms.

II. Mechanical Methods of Pest Management

Mechanical pest management controls pests using mechanical forces such as picking, fences, barriers, or electronic wires. It also includes weeding and alteration of temperature to manage the pests. Mechanical control can be accomplished by following the below methods (Agriculturist, 2018).

1. **Hand picking :** Most common method is the use of human hands to remove insect pests. An insect can be hand-picked and destroyed of its easily accessible to the pickers large and conspicuous and present in many clusters. e.g., Egg

mass of rice stem borer, the early larval stage of caterpillars, adult of sugarcane stem borer, etc., can be maintained by hand and destroyed.

2. **Use of hand nets and bag nets :** Some adult insects can be collected and destroyed with hand nets. e.g., Green leafhopper, Grasshoppers, etc., can be controlled with hand nets when they migrate in AprilMay from maize to sugarcane. The bag nets can be used to control the insects. e.g., Rice hispa from the field partially.

3. **Beating and hooking :** Various household pests like a housefly, cockroach, etc., can be killed by beating with brooms, flappers, etc. Again, some pests that hide in the host's holes or cracks, such as Rhinoceros beetle of coconut, Jackfruit beetles, etc., are killed by hooking with the help of crooked hooks.

4. **Shaking and garring :** Different insects such as cotton bugs, mango shoot borer, and defoliator, etc., can be killed by shaking the small trees or shrubs. Particularly, every in the morning in the cold season when insect remains in the tree and collecting them in a tub containing kerosinized water for the destruction

5. **Sieving and winnowing :** Commonly used against stored grain pest, *e.g.,* red flour beetle are destroyed by collecting them through sieving, and rice weevils are destroyed by collecting them winnowing.

6. **Mechanical exclusion :** Some insects are controlled by creating a barrier for insects in reaching the place where they cause damage. *e.g.,* Application of a band of sticky material like 'Ostico' or a band of slippery sheets like alkathene around the trunk of a mango tree to prevent the upward movement of the mango mealybug. Using of screens over the windows, doors, and ventilators of the house to keep away houseflies, Mosquitoes, bugs, etc. Making trench around the field for the Jute hairy caterpillar, Jute Semilooper, and groundnut red hairy caterpillars from an infested area to new field, Using red light in the monsoon to keep away most of the insects.

7. **Use of mechanical traps :** Various types of traps used for collecting and killing different types of insect

   » **Light trap :** Used to attract and kill the nocturnal insects. e.g., leafhopper, jute hairy caterpillar, moths, stem borer of Rice, etc. An electric bulb or a lamp is placed in the wide flat vessel containing kerosinized in which the moths and beetles get drowned.

   » **Air suction trap** : Used against stored grain pest in the godown.

   » **Electric trap** : Metal screens are used on which birds or insects are electrocuted.

8. **Burning :** locust can be killed by burning with the help of flame torches; stored grain pest are also controlled by burning.
9. **Crushing and grinding :** For this method, devices are utilized for pest removal. Sugarcane shoot borers are controlled by harvesting the sugarcane and then crushing for obtaining sugar.
10. **Sound production :** Mainly used in scaring the birds, which attack fruits and grain crops. This is also used to control some insects like mosquitoes. Male mosquitoes are attracted to the outside of the house by producing the sound of female mosquitoes from outside. Acoustic sensors are used to monitor pest populations in stored grain automatically. Ultrasonic waves successfully managed adult *Sitophilus granaries* inside a wheat grain mass.
11. **Rope dragging in the field :** Rice case worm larva pupate in the case prepared by the leaves which remain adhere to the plant and can be removed by the pulling rope over the crops. Due to this, the case can fall in the stagnating water and be removed easily.
12. **Banding the trees** : Mealybugs of mango come to the soil for egg-laying, which can be prevented by putting sticky bands on the stem of the mango tree.
13. **Bagging the fruits** : Fruit sucking moth on citrus or pomegranate suck the juice with the help of stout, which can be prevented by bagging the fruits.
14. **Trenching the field** : Pests like army worm, hairy caterpillars, and grasshoppers move from one field to another, which can be prevented by trenching in the field.
15. **Tin collars on the stem :** Rats can climb on coconut trees and damage the fruits. When we put the tin collars on the stem, they cannot climb.

Advantages

Skilled labours are not required, the cost required is significantly less, and there are no side effects.

Disadvantages or limitations

Time and labour requirement is high, this method is applied only for the small scale produce and requires repeated application.

III. Physical Methods

In physical methods, the physical environment of the pest is modified so that they no longer pose a threat in crop production and also use devices viz., physical barriers that protect produce or host plants from infestation. They target physiological and behavioral processes.

These methods are grouped into two classes, passive and active. The active class is subdivided into mechanical, thermal, and electromagnetic techniques. A passive method does not require the additional input after establishment to be effective over a given period. The efficacy of active methods depends on continued inputs throughout the management procedure. The level of control achieved is related to the quantity and strength of the inputs. The postharvest conditions are better suited to physical control methods because the environment is rather confined, the material is of high economic value, and insecticides are frequently inappropriate. The cold, heat, and ionizing radiation are widely used as postharvest quarantine treatments (Hallman, 2001).

A. Passive methods

Physical barriers may be defined as any living or nonliving material used to restrict movements or to delineate space. They comprise methods compatible with different control techniques (Metcalf *et al.*, 1962).

1. **Trenches :** They intercept walking insects such as the hairy caterpillars, locust nymphs, and chinch bugs (Metcalf *et al.*, 1962). A V-shaped trench lined with plastic retains up to 95 percent of Colorado potato beetles.

2. **Fences :** Fencing is predominantly relevant to exclude low-flying insects (anthomyiids) from annual crops (e.g., onion and cole crops) (Metcalf *et al.*, 1962). Fences 1 m high exclude 80 percent of flying female cabbage flies, *Delia radicum*. Overhangs (25 cm) decreased cabbage maggot fly, *Delia radicum,* trap catches inside the fenced plots, and reduced damage to the crop (Vernon and Mackenzie, 1998).

3. **Organic mulch :** Straw mulch indirectly affects Colorado potato beetle populations and significantly reduces damage (Zehnder and Hough-Goldstein, 1990) by favoring several species of its egg and larval predators: *Coleomegilla maculata*, *Hippodamia convergens*, *Chrysoparla carnea*, and *Perillus bioculatus* (Brust, 1994).

4. **Mulches from artificial materials :** Artificial materials can be used as mulches for pest control. *e.g.,* thrips are attracted to blue, black, and white plastic materials (Csizinsky *et al.*, 1990), and aphids to yellow and blue color (Csizinsky *et al.*, 1990). Aluminized materials can attract some insect species while repelling others (Begin *et al.*, 2001). The repellent properties have been related to the reflection of

ultraviolet light at wavelengths < 390 nm. In addition, they impact insect pests and reduce weeds, other insects, diseases, and nematodes (Rhainds *et al.*, 2001).

5. **Particle films :** The recent advance of kaolin as spray formulation under the generic name 'particle film technology' demonstrated the broader insecticidal activity (Puterka *et al.*, 2000). For example, the Spirea aphids, *Aphis spiraecola*, lost footing and fell off the treated plant, and damage by the potato leafhopper, *Empoasca fabae*, was significantly reduced (Glenn *et al.*, 1999). Hydrophobic PF also deterred feeding and oviposition by citrus root weevil, *Diaprepes abbreviatus* (Lapointe, 2000).

6. **Inert dusts :** There are many kinds of inert dusts *viz.,* lime, common salt, sand, kaolin, paddy husk ash, wood ash, clays, diatomaceous earth (ca. 90% SiO_2), synthetic and precipitated silicates (ca. 98 % SiO_2), and silica aerogels. Because of their low mammalian toxicity, they are used to protect stored grains against a number of coleopteran pests. Diatomaceous earth is classified as a 'generally recognized as safe' (GRAS) food additive.

7. **Oils :** Till date, no resistance has been reported against mineral oils. Although oils primarily act as contact poison by obstruction of the respiratory system (hypoxia); they sometimes also act as a repellent to egg-laying females. Several arthropods are affected, e.g., mites, scale insects, mealybugs, psyllids, aphids, leafhoppers, and some lepidopteran pests such as eggs of codling moths. Due to their lower residual activity, they are relatively harmless to beneficial insects. Horticultural mineral oils are optimized for good adjuvant and insecticidal activities and off-target spray drift management (Jacques and Kuhlmann, 2002).

8. **Surfactants and soaps :** Surfactants may have direct or indirect effects on soft-bodied arthropods. For example, Cowles *et al.* (Cowles *et al.*, 2000) demonstrated that trisiloxane, an inert ingredient, suffocates or disrupts major physiological processes in *Tetranychus urticae*. Owing to their surfactant properties, they work as soaps, presumably allowing interaction of water with arthropod cuticles and causing drowning by permitting water to infiltrate tracheae, *e.g.,* Fish Oil Rosin Soap (FORS).

B. Active methods

1. Mechanical

a. **Cleaning :** When prescribed as a quarantine treatment, the popular postharvest treatment is usually followed by an inspection by the importing regulatory agencies to ensure that the cleaning successfully removes undesired pests and debris.

b. Polishing : It is an industrial process consisting of rubbing off the pericarp of food grains. Polishing to a weight loss of 11 percent of rice grains causes 40 percent acute egg mortality in rice weevil, *Sitophilus oryzae*, followed by 40 percent mortality due to their poor suitability as host (Lucas and Riudavets, 2000).

c. Thermal : Temperature control is widely used during post-harvest stage to slow down the degradation of produce caused by physiological processes, pathogens, and insects. The use of kinetic models with intrinsic thermal mortality is a promising approach to implement high-temperature short-time thermal treatments in quarantine stations (Tang *et al.*, 2000).

d. Cold storage : It is one of the oldest and extensively used quarantine treatments in the storage of fresh commodities (fruits and vegetables) at -0.6 to 3.3 for 7 to 90 days, depending on the pest and temperature. Cold storage can be employed post packaging and also in slow transit, such as in ships. Freezing for at least one day will generally kill most non-diapause stages of insects, whereas quick freezing at temperatures ≤ -15 can also destroy diapausing insects.

e. Heated air : Exposing commodities to hot air at 43 to 52 for a few hours. Heated-air treatments are not suitable for temperature-sensitive temperate fruits. Dry air treatments at temperatures higher than those used for fresh produce (up to 100) are being practiced to treat agricultural products, namely meal, grain, straw, and dried plants.

f. Hot-water immersion : Immersion at 43 to 55 ranging from a few minutes to a few hours is practiced to eliminate several arthropods and nematodes on plant-propagative materials. It is a simple, economical, and rapid treatment. Temperate fruits are damaged when immersed in water hot enough to kill insects.

g. Flaming : Flame throwers are used to kill locust swarms on host trees. When treating with a propane flamer, the thermo-sensitivity of the target insect and host plant should be considered such that the temperature allows only the destruction of pests without harming the crop, e.g., 70 for Colorado potato beetle adults (Duchesne *et al.*, 2001).

h. Steaming : Under field conditions, the steaming works on insects in a similar way to flaming. Works on the fact that legs can be damaged by exposing to temperature of 68 to 75 and those muscles of the legs are inactivated by dipping the insect from 0.2 to 0.4 second in hot water.

i. Solar heating : A solar heater made of dark cloth and translucent plastic sheeting has been tested for bruchid control in stored grains. As all stages of the cowpea weevil, Callosobruchus maculatus, inside grains are destroyed at a higher temperature of >60 for approximately I hour 40 minutes. All stages of Callosobruchus spp. were killed when pigeon pea was solarized in polyethylene bags in India with minimal effect on grain germination (Chauhan and Ghaffar, 2002).

j. **Electromagnetic radiation :** Transfers energy from a source to target without the use of energy transfer fluid. Ionizing atoms can absorb electromagnetic energy at the target site or by inducing vibration of charged particles within the matter, thereby enhancing temperature due to internal friction (Lewandowski, 2001).

k. **Irradiation :** Ionizing radiation provided by cobalt 60 or cesium 137 is an effective quarantine treatment. Radiation is effective at halting pest development or providing sterility at tolerable doses by fresh commodities.

l. **Radiofrequency heating (RF)** : A part of the electromagnetic spectrum spans roughly 3 kHz to 300 GHz. RF heating is used as a quarantine treatment against pests in dry fruits (Wang *et al.*, 2001), where the insect would have much higher moisture content than its host and thus be more susceptible to RF heating, especially at lower frequencies of 10-100 MHz.

m. **Infrared heating :** Can disinfest grains provided that the product is exposed in a thin (ca. 2 cm) layer.

C. Combination of methods

1. **Heat and controlled atmospheres** : The low-oxygen and high-carbon dioxide atmospheres in airtight containers have a higher efficacy rate when the temperature is elevated to levels that cause hyperactivity. Hence, when we use the combination of heat and controlled atmosphere storage techniques, the time required for the disinfestation process can be reduced even for carbon dioxide concentration insensitive species, *i.e., Tribolium confusum* (Buscarlet, 1993).

b. **High pressure and modified atmospheres :** The combination of pressure ranging from 2 to 5 MPa in an autoclave with a carbon dioxide–enriched atmosphere allows a complete disinfestation of raw material (e.g., pet food, spices, and aromatic plants) packaged in non-airtight containers in less than 4 hours exposure (Reichmuth and Wohlgemuth,1994).

c. **Modified atmosphere and packaging :** The modified atmospheres with high (50–60% v/v) carbon dioxide content or low (<1% v/v) oxygen content are effective methods when food products are stored in an airtight enclosure

(Fleurat-Lessard, 1990). They are mainly used with high-value commodities such as dried fruits or cut flowers.

IV. Biological Method

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, (d) Insect growth regulators, and (e) Transgenic Organisms.

A. Biological control : The suppression of reproductive organisms through the actions of parasites, predators, or pathogens to restrict pest population at a lower average density. There are three different approaches to biological control: importation, augmentation, and conservation.

1. **Importation** : Involves the enforcement of the native natural enemies of an exotic pest to a new location where the pest does not inhabit naturally. The procedure consists of the identification of pest origin and, consequently, exploring specific, effective, and associated natural enemies of crop pests. Selected natural enemies are then passed through various assessments, testing, and quarantine procedures to ensure their appropriate use. Finally, the selected natural enemies are mass-produced and distributed for pest control (Polosky, 2015).

2. **Augmentation** : Is the supplemental release of natural enemies to boost up the inhabitant population of natural enemies. In addition, the cropping system may also be modified to augment natural enemies called habitat manipulation or ecological engineering. The release of natural enemies in small numbers during the critical time of the crop season is called inoculative release (e.g., *Encarsia formosa*, a parasitoid, is released periodically to control greenhouse whitefly). On the contrary, the inundative release refers to the release of natural enemies in larger quantities. Lady bird beetles and lacewings are released against mealybugs in fruit crops or parasitoids such as Trichogramma for rice or sugar cane borers management at frequent intervals. Entomopathogenic nematodes are released at rates of millions and even billions per acre for controlling certain soil-dwelling insect pests.

3. **Conservation :** When natural enemies are already adapted to the given habitat and target pests, their conservation becomes cost-effective and straightforward. An example of such a cost-effectiveness technique 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 to 100 folds. This, in turn, reduces the necessity to spray insecticides by 70 percent and boosts overall crop yield by 5 percent (Zhu, 2014). Habitat manipulation is the modification of the cropping system to favor natural enemies by providing a suitable habitat such as a shelterbelt, hedge grow, or beetle bank, where beneficial insects can live and reproduce.

B. Biopesticides : Certain types of pesticides derived from natural materials such as animals, plants, bacteria, and certain minerals.

Classification of biopesticides : (1) Microbial pesticides (2) Plant-incorporated protectants, (3) Biochemical pesticides or herbal pesticides and (4) Animal based pesticides.

1. **Microbial pesticides :** Are those which consist of microorganisms (*e.g.*, bacterium, fungus, virus, nematode, and protozoa) as an active ingredient and are used to control different types of pests. Each active ingredient is specific to its target pest. The most widely used microbial pesticides are subspecies and strains of *Bacillus thuringiensis* (Bt) (Kalra and Khanuja, 2007).

2. **Plant incorporated protectants (PIPs) :** Pesticidal substances, which are produced from the genetic materials of plants. These materials are produced by employing genetic engineering techniques. For example, a gene from the Bt pesticidal crystal toxin protein can be introduced into the plant's genetic material. The plant then produces substances that destroy the pests.

3. **Biochemical pesticides or herbal pesticides :** Naturally occurring substances that control pests and microbial diseases. Biochemical pesticides are often called botanical pesticides when they are derived from plant extracts include substances like insect sex pheromones and various scented plant extracts. *e.g.,* Neem oil, NSKE, Neem cake, and pyrethrins.

4. **Animal based pesticides :** Marine annelids derived Nereistoxin and Cartap hydrochloride are widely used to manage lepidopteran pests in Rice. Cow urine (20 %) and cow dung extracts can be used for pest management due to their antifeedant and repellant properties. Besides this, cow urine is the key ingredient in different plant-based indigenous decoctions/extractions/formulations *viz.* Chili-garlic extract, Neemastra, Agniastra, Bramhastra, and Dashaparni Kashaya in natural farming or organic crop protection.

C. Semiochemicals : Semiochemicals are attributed to interspecific and intraspecific interactions, which are categorized as allelochemicals and pheromones, respectively (Rathore and Nollet, 2012). The allelochemicals are classified as allomones, kairomones, and synomones. Allomones are often found in nature as part of 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. Kairomones benefit many predators and bugs by guiding them to prey or potential host insects. Synomones are compounds that are beneficial to both the receiver and the sender.

One member of a species releases pheromones to cause a specific interaction with another member of the same species. Pheromones may be further classified based on 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. 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.

D. 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. Resistance against plant pathogens has been achieved by transferring genes from viruses into plants, bacteria, fungi, and other plants and insects. Herbicide-resistant transgenic crops allow chemical weed control without harming the crop plant (Kuiper *et al.*, 2000).

E. Insect growth regulators (IGR) : Defined as the chemicals that are natural or synthetic that regulate growth in insects. Insect growth and development are mainly managed by three important hormones: brain harmone, juvenile hormone, and moulting hormone. Commercially available juvenoids are Fenoxycarb (available: Insegar, Logic, Torus), effective against Blattidae, Coccoidae, Culicidae, Lepidoptera, Psyllidae, ants, and Siphonaptera. Pyriproxyfen (available as sumilarv & admiral) is used to manage Blatellidae, Coccoidae, Diptera and Siphonoptera.

Ecdysones are used as insecticides, ecdysteroid bisacyhydrazine agonists act as insecticides. RH-5849 is the first bisacyhydrazine compound to bind with ecdysteroid receptors, RH-5992 (tebufenozide), RH-0345 (halofenozide), and RH-2485 (methoxyfenozide). Synthetic chitin synthesis inhibitors are grouped into benzyl phenyl ureas (Diflubenzuron effective against beetles, weevils, flies, moths & butteflies), thiadiazinone (buprofezin), triazines (cyromazine- against dipterans), phenyl carbamate (barbane), synthetic pyrethroid (Permethrin), and also from naturally through microorganisms, *streptomycine cacoi* and *S. tendae*. Plumbagin and azadirachtin are the plant origin chitin synthesis inhibitors.

V. Integrated Pest Management (IPM)

It aims to eliminate or drastically reduce the use of pesticides and minimize the toxicity of and exposure to any products used. IPM utilizes various methods and techniques, including cultural, physical, mechanical, biological, and chemical strategies, to control a multitude of pest problems. Non-integrated pest control programs tend to focus on killing pests without considering the reason behind the pests' existence in the first place.

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 IPM are reported to follow a four-tiered approach

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. However, the level at which pests will become an economic threat is critical to guide future pest control decisions.

2. **Monitoring and identifying pests :** 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 possibility of unnecessary and inappropriate pesticide usage.

3. **Prevention :** As a first line of pest control, IPM programs manages the crop, lawn, or indoor space to prevent pests from becoming a threat. This may mean using cultural methods in an agricultural crop, 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 the environment.

4. **Control :** Once monitoring, identification, and action thresholds identify the improvement of the pest control method, IPM programs then evaluate the proper control method for effectiveness and risk. Effective techniques with minimum risk are preferred, which include targeted chemicals or mechanical control. Additional pest control methods, such as targeted spraying, are only employed if monitoring, identification, and action thresholds indicate lower-risk controls are not working (Integrated Pest Management (IPM) Principles, 2016).

Conclusion

Excessive use of synthetic pesticides has caused contamination of food and groundwater sources and harmful effects on beneficial insects. Chemical insecticides have been connected to many health hazards, including neurologic and hormone system disorders, congenital disabilities, and cause cancer. The need to understand and awareness of the dangerous effects of pesticides on human health and the environment is the demand for alternatives to pesticides. Some approved and practiced alternatives to pesticide usage include pest problems within a broad context, including natural enemies. Now a day's many farmers follow integrated pest management practices as an alternative to chemicals. IPM is most suitable for developing countries like India. In IPM schedule use of chemical insecticides are the last approach; before that, IPM encourages to follow cultural, mechanical, physical, and biological. This IPM concept helps in the reduction of chemical pesticide usage. In the IPM programme, there are no harmful effects viz., human health, environmental contamination, and beneficial insects compared to non IPM practices.

References

Agriculturist Musa. June 11, 2018.

APHIS. 1998. Treatment Manual. Frederick, MD: USDA.

Begin, S., Dube, S.L. and Calandriello, J. 2001. Mulching and plasticulture. See Ref. 101, pp. 215–23.

Boiteau, G. and Vernon, R. S. 2001, Physical barriers for the control of insect pests. See. Ref., 101:224–247.

Bomford, M. K., Vernon, R. S. and Pats, P. 2000. Importance of overhangs on the efficacy of exclusion fences for managing cabbage flies (Diptera: Anthomyiidae). *Environ. Entomol.*, 29:795–99.

Brust, G. E. 1994, Natural enemies in straw mulch reduce Colorado potato beetle populations and damage in potato. *Biol. Control.*, 4:163–69.

Buscarlet, L.A. 1993. Study on the influence of temperature on the mortality of Tribolium confusum exposed to carbon dioxide or nitrogen. *J. Z. Naturforsch.* 48c: 590–94.

Chauhan, Y.S and Ghaffar, M.A. 2002. Solar heating of seeds a low cost method to control bruchid (Callosobruchus spp.) attack during storage pigeonpea. *J. Stored Prod. Res*. 38:87–91.

Cowles RS, Cowles EA, McDermott AM, Ramoutar D. 2000. "Inert" formulation ingredients with activity: toxicity of trisiloxane surfactant solutions to two spotted spider mites (Acari: Tetranychidae). *J. Econ. Entomol.* 93:180–88.

Csizinsky, A. A., Schuster, D. J. and Kring, J. B., 1990. Effect of mulch color on tomato yields and on insect vectors. *Hort. science,* 25:113.

Duchesne, R.M., Lague, C., Khelifi, M. and Gill, J. 2001. Thermal control of the Colorado potato beetle. See Ref. 101, pp. 61–73.

Fleurat Lessard, F. 1990. Resistance des emballages de denrees alimentaires aux perforations par des insectes nuisibles. Methodes detude et protocoles experimentaux. *Sci. Aliment*. 10:5–16.

Glenn, D.M., Puterka, G.M., Vanderzwet, T., Byers, R.E. and Feldhake, C. 1999. Hydrophobic particle films: a new paradigm for suppression of arthropod pests and plant diseases. *J. Econ. Entomol.* 92:759–71

Hallman, G. J. 2001, Irradiation as a quarantine treatment. In Food Irradiation: Principles and Applications, ed. R Molins, New York: Wiley. pp.113-130.

Integrated Pest Management (IPM) Principles, 2016. Available from: https://www.epa.gov/safepestcontrol/integrated-pest-management-ipm-principles

Jacques, D.F. and Kuhlmann, B. 2002. Exxon Esso experience with horticultural mineral oils. In Spray Oils Beyond 2000, ed. GAC Beattie, DM Watson, ML Steven, DJ Rae, RN Spooner-Hart, pp. 39–51. Hawkesbury, Aust.: Univ. West. Syd.

Kalra, A. and Khanuja, S. 2007. In Business potential for agricultural biotechnology. Research and development priorities for biopesticide and biofertiliser products for sustainable agriculture in India, Asian productivity organization (APO), Tokyo, Japan. pp: 96–102.

Kuiper, H. A., Kleter, G. A. and Noordam, M.Y. 2000. Risks of the release of transgenic herbicide-resistant plants with respect to humans, animals, and the environment. *Crop. Prot.,* 19(8): 773–778.

Lapointe, S.L. 2000. Particle film deters oviposition by Diaprepes abbreviatus (Coleoptera: Curculionidae). J. Econ. Entomol. 93:1459–63.

Lewandowski, J. 2001. Electromagnetic radiation for plant protection. See Ref. 101, pp. 111–24.

Lucas E, Riudavets J. 2000. Lethal and sublethal effects of rice polishing process on *Sitophilus oryzae* (Coleoptera: Curculionidae). *J. Econ. Entomol.,* 93:1837– 41

Metcalf, C. L., Flint, W. P. and Metcalf, R. L. 1962. Destructive and useful insects, their habits and control. New York: McGraw Hill. pp. 1087.

Mokhele, T. A. 2011. Potential health effects of pesticide use on farm workers in Lesotho. *S. Afr. J. Sci.,* 107: 29–35.

Polosky, Z. 2015. 21st Century Homestead: Biological Pest Control.

Puterka, G.J., Glenn, D.M., Sekutowski, D.G., Unruh, T.R. and Jones, S.K. 2000. Progress toward liquid formulations of particle films for insect and disease control in pear. *Environ. Entomol*. 29:329–39

Rathore, H. S. and Nollet, L. M. 2012. Pesticides: evaluation of environmental pollution. CRC Press, Boca Raton.

Reichmuth, C. and Wohlgemuth, R. 1994. Carbon dioxide under high pressure of 15 bar and 20 bar to control the eggs of the Indian meal moth Plodia interpunctella (H¨ubner) (Lepidoptera: Pyralidae) as the most tolerant stage at 25◦C. In Stored Product Protection, ed. E Highley, J Wright, HJ Banks, BR Champ, 1:163–72. Wallingford, UK: CABI.

Rhainds, M., Kovach, J., Dosa, E.L. and EnglishLoeb, G. 2001. Impact of reflective mulch on yield of strawberry plants and incidence of damage by tarnished plant bug (Heteroptera: Miridae). *J. Econ. Entomol*., 94:1477–84

Tang, J., Ikediala, J.N., Wang, S., Hansen, J.D. and Cavalieri, R.P. 2000. High-temperature short-time thermal quarantine methods. *Postharvest Biol. Technol.* 21:129–45.

Vernon, R. S. and Mackenzie, J. R. 1998. The effects of exclusion fences on the colonization of rutabagas by cabbage flies (Diptera: Anthomyiidae). *Can. Entomol.,*130: 153–62.

Wang, S., Ikediala, J.N., Tang, J., Hansen, J.D. and Mitcham, E. 2001. Radio frequency treatments to control codling moth in in shell walnuts. *Postharvest Biol. Technol*., 22:29–38

Zehnder, G. W. and Hough-Goldstein, J. 1990, Colorado potato beetle (Coleoptera: Chrysomelidae) population development and effects on yield of potatoes with and without straw mulch. *J. Econ. Entomol.,* 83:1982–1987

Zhu, P. 2014. Selection of nectar plants for use in ecological engineering to promote biological control of rice pests by the predatory bug, *Cyrtorhinus lividipennis*, (Heteroptera: Miridae). *PLoS One*, 9(9): 108-669.

Chapter - 16

Prospectus of Organic Farming in India

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Introduction

Organic farming may be a method of a farming system which primarily aimed toward cultivating the land and raising crops in such how on keep the soil alive and in healthiness by use of organic wastes (crop, animal and farm wastes, aquatic wastes) and other biological materials alongside beneficial microbes (bio-fertilizers) to release nutrients to crops for increased sustainable production in an eco-friendly pollution-free environment (Narayanan, 2005; Guruswamy and Gurunathan,2010; Makadiaand Patel, 2015).

As per the definition of the U.S. Department of Agriculture (USDA), study team on organic farming "organic farming could also be a system which avoids or largely excludes the use of synthetic inputs (such as fertilizers, pesticides, hormones, feed additives, etc.) and to the utmost extent feasible depends on crop rotations, crop residues, animal manures, off-farm organic waste, mineral grade rock additives and biological system of nutrient mobilization and plant protection." Organic farming sustains the health of people, soil systems, and ecosystems by depending upon ecological processes and biodiversity adapted to local conditions rather than using inputs with adverse effects. Organic farming combines tradition, innovation, and science to profit the environment and promotes fair relationships for all involved.

According to the Union Ministry of Agriculture and Farmers Welfare, Government of India (as of March 2020), approximately 78 million hectares of farms have been under organic farming, which is 2 % of the 140.1 million hectares of Net sown area. A few states have taken the lead in enhancing the coverage of organic farming. Madhya Pradesh tops the list among the states with 0.76 million hectares of organic farming, which is quite 27 % of India's total organic farmland.

Madhya Pradesh, alongside Rajasthan and Maharashtra, accounts for about half the area under organic farming.

Principles of Organic Farming

Organic farming and food processing practices are wide-ranging and necessitate socially, ecologically, and economically sustainable food production systems. The International Federation of Organic Agriculture Movements (IFOAM) has suggested the essential four principles of organic farming, i.e., the principle of health, ecology, fairness, and care. The primarily practices and principles of organic food production are to inspire and enhance biological cycles within the farming system, keep and enhance deep-rooted soil fertility, reduce all kinds of pollution, evade the appliance of pesticides and artificial fertilizers, conserve genetic diversity in food, consider the vast socio-ecological impact of food production, and produce high-quality food in sufficient quantity (IFOAM,1998).

Consistent with the National Organic Programme implemented by USDA Organic Food Production Act (OFPA, 1990), agriculture needs specific prerequisites for both crop cultivation and rearing of animals. To be acceptable as organic, crops should be cultivated in lands with none synthetic pesticides, chemical fertilizers, and herbicides for 3 years before harvesting with enough buffer zone to lower contamination from the adjacent farms. Genetically engineered products, sewage sludge, and radiation are strictly prohibited. The soil's fertility and nutrient content are managed primarily by farming practices, with crop rotation, and using cover crops that are boosted with animal and plant waste manures. Pests, diseases, and weeds are mainly controlled with physical and biological control systems without using herbicides and artificial pesticides. Organic livestock should be reared barren of scheduled application of growth hormones or antibiotics, and that they should be given enough access to the outdoor. Preventive health practices like routine vaccination, vitamins, and minerals supplementation also are needed (OFPA, 1990).

Organic Farming in India

Historical background

The concept of organic agriculture isn't alien to India. The primary scientific approach to organic farming dates back to the Vedas of the later Vedic period. The essence of which is to measure compatibility with, instead of exploiting Mother Nature. There's a quick mention of several organic inputs in our ancient literature like Rigveda, Ramayana, Mahabharata, Kautilya, Arthasashthra, etc. organic agriculture has its roots in traditional agricultural practices evolved in countless villages and farming communities over the millennium. Empirical evidence suggests that while conventional agriculture improves with significant holdings, organic farming functions better in small farms. A study by Gupta and Verma (1997), comparing grain production in organic vis-àvis conventional methods, observed that as farm size increases, the benefits of organic rotation subsided visibly. Further, the study reported that organic farming was more profitable and productive on a smaller scale than conventional farming.

Government initiatives

The lucrative market of the developed world has thus far acted because of the primary drives behind the 'certified organic' sector, which remains during a nascent stage in India. Consistent with one estimate, in 1999, merely 0.001 percent of the entire agricultural land in India was under certified organic cultivation. It's predominantly the N.G.O.s and people's organizations spearheading the organic agriculture movement in several parts of the country during the last 20 years.

The Govt. of India has found a special cell under the Agricultural and Processed Food Export Development Authority (APEDA) of the Ministry of Commerce and Industries (MOCI). The MOCI began with the 'National Programme of Organic Products' (NPOP) in 2000 and the 'India Organic' logo in 2002. While these initiatives are undertaken to market exports of Indian organic products, the Department of Agriculture and Cooperation has formulated a 'National Project on Organic Farming' to organic market agriculture as a part of an exercise to curb the utilization of chemical pesticides and make the agricultural activity more eco-friendly. Shifting to organic farming, even though it promises higher returns in terms of higher prices and international acceptability, within the end of the day, might not be preferred by the bulk of farmers as they're hooked into the farm for livelihood, and any departure would affect them immediately. To form a majority of small farmers shifting to organic farming, several subsidies tend to concentrate on organic inputs. Such initiatives are a step within the right direction, but they ought to be weighed against the large subsidies that the Central Government has been providing for the assembly and import of chemical fertilizers and pesticides. There's an excellent potential for organic farming to flourish, and given an appropriate institutional and policy framework, it'll not be challenging to market the prevailing 'de-facto organic' farms to the category of certified organic farms. This would enable the marginal farmers to require advantage of the lucrative marketplace for certified organic products within the developed world, which could directly contribute to developing their economic well-being.

Status of organic farming in India

According to data released by the Union Ministry of Agriculture and Farmers Welfare on March 2020 for the year 2019, near about 2.78 million hectares of farmland were under organic cultivation; this is only 2 % of the 140.1 million ha net sown area in the country. This data shows organic farming in India is at its nascent stage, and it has lots of scope for growth, and it needs to take more efforts to cover more area under organic farming. In India during 2002, organic farming production was about 14 000 tonnes, of which 85 % of it had been exported (Chopra *et al.*, 2013). The crucial main barrier considered within the progress of organic agriculture in India was the cavities within the government policies of creating a firm decision to market organic agriculture. Moreover, there have been several significant drawbacks within the growth of organic farming in India, which include lack of awareness, lack of excellent marketing policies, shortage of biomass, inadequate farming infrastructure, high input cost of farming, inappropriate marketing of organic input, inefficient agricultural policies, lack of monetary support, incapability of meeting export demand, lack of quality manure, and low yield (Bhardwaj and Dhiman, 2019).

In India, few states have taken the lead in improving organic farming status and coverage, as a significant part of this area is concentrated only in a handful of states. Madhya Pradesh tops the list with 0.76 million ha of the area under organic cultivation, a. i., over 27 percent of India's total organic cultivation area, followed by Rajasthan (0.35 million ha) and Maharashtra (0.28 million ha). These only three states account for about 50 % of the total area under organic cultivation in India. The states with total organic cultivation area and net sown area are listed below (Amit Khurana and Vineet Kumar. 2020).

Table 1. The area under organic farming Indian States and Union Territories.

S. No.	State/Union Territory	Total Organic area (000 ha) in 2019	An organic area as a Net sown area of that state/ Union territory in 2019 (%)
1	Madhya Pradesh	756	4.9
2	Rajasthan	350	2.0
3	Maharashtra	284	1.6
4	Andhra Pradesh	144	2.3
5	Uttarakhand	128	18.2
6	Odhisha	118	2.6

7	Karnataka	111	1.1
8	Gujarat	103	1.0
9	Uttar Pradesh	79	0.5
10	Sikkim	155	100
11	Chhattisgarh	71	1.5
12	Meghalaya	56	19.5
13	Kerala	54	2.7
14	Assam	43	1.5
15	Jharkhand	31	2.2
16	Tamil Nadu	30	0.6
17	Telangana	28	0.6
18	Jammu and Kashmir	26	3.4
19	Goa	23	18.1
20	Nagaland	23	6.0
21	Aurnachal Pradesh	22	9.8
22	Manipur	19	5.0
23	Himachal Pradesh	18	3.3
24	Punjab	17	0.4
25	Mizoram	14	10.0
26	Bihar	12	0.2
27	Delhi	10	45.5
28	Dadar and Nagar Haveli	10	53
29	Andaman and Nicobar	9	60
30	West Bengal	9	0.2
31	Tripura	9	3.4
32	Haryana	7	0.2
33	Lakshadweep	3	-100
34	Chandigarh	3	-100
35	Daman and Diu	1	32
36	Puducherry	1	8
Total		2777	-

(MoA & F.W., G.O.I., India)

Sikkim has been the only Indian state to possess fully become organic. A majority of states have only a little part of their Net sown area under organic farming. Even the uppermost three states (Madhya Pradesh, Rajasthan, and Maharashtra) that account for the most important area under organic cultivation have around 4.9 %, 2.0 %, and 1.6 % respectively of their Net sown area under organic farming. Some states like Meghalaya, Mizoram, Uttarakhand, Goa, and Sikkim have 10 % or more of their Net sown area under organic farming. All of those states dwell the hilly areas, except Goa. Most of the other states have below 10 % of their Net sown area under organic farming. Union territories like Delhi, Chandigarh, Dadra and Nagar Haveli, Lakshadweep, Andaman & Nicobar, and Daman and Diu have 10 % or more of their Net sown area under organic farming, but their agricultural area is relatively minimal (Indian Express, 2016). The Govt. of India has recently implemented several programs and schemes for enhancing organic farming within the country. Among these, the foremost important includes

» The Paramparagat Krishi Vikas Yojana (PKVY)

» Organic Value Chain Development in North Eastern Region Scheme,

» Rashtriya Krishi Vikas Yojana (RKVY)

» The Mission for Integrated Development of Horticulture (MIDH)

» National Horticulture Mission (N.H.M.)

» Horticulture Mission for North East and Himalayan States (HMNEH)

» National Bamboo Mission (N.B.M.)

» National Horticulture Board (N.H.B.), Gurugram, Hariyana

» Coconut Development Board (C.D.B.), Kochi, Kerala

» Central Institute for Horticulture (CIH), Medziphema, Nagaland

» National Programme for Organic Production (NPOP)

» National Project on Organic Farming (NPOF)

» National Mission for Sustainable Agriculture (NMSA)

India's topmost organic state Madhya Pradesh has nearly 90 % of its organic area under NPOP. The leading three states like Madhya Pradesh, Rajasthan, and Maharashtra, collectively have quite 80 % of their organic area coverage under NPOP. Only a couple of states like Telangana, Bihar, Uttarakhand, and Andhra Pradesh, are covered more by PKVY than NPOP. The 78 million hectares area covered under organic farming in India is about 2 % of the 140.1 million hectares of Net sown area within the country; 94 million hectares area under National Programme for Organic Production (NPOP), 7 million hectares area under Mission Organic Value Chain Development for North Eastern Regions (MOVCD) and 59 million hectares area under Paramparagat Krishi Vikas Yojna (PKVY). NPOP scheme began in 2001 and covered nearly 70 % of India's total organic area coverage, of which 30 % is under conversion. NPOP aims to supply the means of evaluating certification programs for organic farming and its products. It aims to encourage the event of organic farming and processing and would be implemented by APEDA. Beginning in 2015 to 2016, PKVY and MOVCD schemes cover 21.5 % and 2.6 %, respectively, of India's total organic area coverage. PKVY is an elaborated component of Soil Health Management of the National Mission of Sustainable Agriculture (NMSA), while MOVCD certainly is a Central Sector Scheme, a sub-mission under NMSA, and aims to develop certified organic production.

Zero Budget Natural Farming (ZBNF) may be a method of farming where the value of growing and harvesting plants is zero because it reduces costs of cultivation through eliminating external inputs and using local resources to rejuvenate soils and restore ecosystem health through diverse, multi-layered cropping systems. It requires only 10 % of water and 10 % electricity but chemical and organic farming. The micro-organisms of trash (300–500 crores of beneficial micro-organisms per one gram cow dung) decompose the dried biomass on the soil and convert it into ready-to-use nutrients for plants. Paramparagat Krishi Vikas Yojana since 2015–16 and Rashtriya Krishi Vikas Yojana are the government schemes. Of India under the ZBNF policy (Sobhana *et al.*, 2019).

India ranked 8th concerning the land of organic agriculture and 88th within the ratio of organic crops to agricultural land as per Agricultural and Processed Food Products Export Development Authority (APEDA) and report of Research Institute of Organic Agriculture (RIOA) (Chopra *et al.*, 2013; Willer and Lernoud, 2017). But a significant growth within the organic sector in India has been observed (Willer and Lernoud, 2017) within the last decades. There have been a couple of threefold increases from 528 171 ha in 2007–08 to 1.2 million ha of cultivable land in 2014–15. India's leading states involved in organic agriculture are Gujarat, Kerala, Karnataka, Uttarakhand, Sikkim, Rajasthan, Maharashtra, Tamil Nadu Madhya Pradesh, and Himachal Pradesh (Chandrashekar, 2010). As per the study conducted by the Associated Chambers of Commerce & Industry in India, the organic food turnover is increasing at about 25 % annually and thereby is expected to achieve

USD 1.36 billion in 2020 from USD 0.36 billion in 2014 (Willer and Lernoud, 2017). Indian Competence Centre for Organic Agriculture cited that the worldwide marketplace for organically grown foods is USD 26 billion, increasing to the extent of USD 102 billion by 2020 (Chopra *et al.*, 2013). Organic foods became one among the rapidly growing food markets, with revenue increasing by nearly 20% annually since 1990 (Winter and Davis, 2006). The worldwide organic foodstuff reached USD 81.6 billion in 2015 from USD 17.9 billion during the year 2000, most of which showed double-digit growth rates (Willer and Lernoud, 2019).

Government policies is not enough for organic coverage

Low organic farming coverage prevails in several states, despite at least 20 of them having a policy or a scheme concerning organic farming. States like Sikkim, Andhra Pradesh, Himachal Pradesh, Kerala, Uttarakhand, Mizoram, Nagaland, and Arunachal Pradesh have expressed their desire to become fully organic or natural-farming states. Apart from the states with 100 percent organic ambition, only a select few have set specific, measurable targets. Some states have had a policy for several years but have not covered many absolute terms under organic cultivation. For example, Karnataka and Kerala have had an organic policy since 2004 and 2010 but have only 1.1 and 2.7 percent of their Net sown area organically cultivated (Amit Khurana and Vineet Kumar. 2020).

On the other hand, states such as Rajasthan, which formulated their policy recently, have covered a significant area. This also indicates that the conversion to the organic area in states may have started much before enacting the policy. Currently, only around 12 states such as Madhya Pradesh, Gujarat, Telangana, Sikkim, Bihar, Karnataka, Odisha, Rajasthan, Uttarakhand, Chhattisgarh, Tamil Nadu, and Uttar Pradesh have their own state organic certification agencies accredited by Agricultural and Processed Food Products Export Development Authority (APEDA). Some states have either developed or are still in the process of forming organic brands such as M.P. Organic, Organic Rajasthan, Nasik Organic, Bastar Naturals, Kerala Naturals, Jaivik Jharkhand, Naga Organic, Organic Arunachal, Organic Manipur, Tripura Organic, and Five Rivers by Punjab (Amit Khurana and Vineet Kumar. 2020).

Fig 16.1 Popular brands of organic products in India

Commodities produced in India under organic farming

- **Commodity :** Tea, coffee, rice, wheat
- **Spices :** Cardamom, black pepper, white pepper, ginger, turmeric, vanilla, mustard, tamarind, clove, cinnamon, nutmeg, mace, chili
- **Pluses :** Red gram, black gram
- **Fruits :** Mango, banana, pineapple, passion fruit, sugarcane, orange, cashew nut, walnut
- **Vegetables :** Okra, brinjal, garlic, onion, tomato, potato
- **Oilseeds :** Sesame, castor, sunflower
- Others Cotton, herbal extracts

Products that Indian production features a comparative advantage

India existence a country with different agro-climatic zones; each state produces its specialty products (Shetty *et al.*, 2014). India has comparative advantages for organic production such as-

1. India is robust in the high-quality production of certain crops like tea, spices, rice specialties, ayurvedic herbs, etc.

2. India features a rich heritage of agricultural traditions that are suitable for designing organic production systems. Sophisticated crop rotation or mixed cropping patterns, for instance, the famous agroforestry systems of the Western Ghats, facilitate the management of pests, diseases, and nutrient recycling. Botanical preparations, several of which originate from the traditional Veda scripts, provide a premier source for locally adapted pest and disease management techniques. The widespread cultivation of legume crops facilitates the availability of biologically fixed nitrogen.

3. In several regions of Indian agriculture isn't very intensive as regards the utilization of agrochemicals. Especially in mountain areas and tribal areas, the utilization of agrochemicals is relatively low, which facilitates conversion to organic production. On these marginal soils, organic production techniques have proved to realize comparable or, in some cases (especially within the humid tropics), even higher yields than conventional farming.

4. Compared to input costs, labour is comparatively cheap in India, thus favoring the conversion to less input-dependent but more labor-intensive production systems, provided they achieve sufficient yields.

5. The N.G.O. sector in India is strong and has established close linkages to an excessive number of marginal farmers. Many N.G.O.s are engaged in promoting organic farming and supply training, extension services information, and marketing services to farming communities.

6. The Indian Government has realized the potential significance of organic agriculture for the country and has recently begun to support organic agriculture on an outsized scale and various levels. A national regulatory framework (standards, accreditation regulations) has already been passed in 2000. There are various schemes and events to support and facilitate exports of organic products (e.g., the massive conference 'Indian Organic Products – Global Markets' held in Delhi in December 2002, mainly sponsored by the Indian Government). The Ministry of Agriculture announced that various sorts of support for organic producers, processors, and traders were to be included within the newest five-year plan.

Organic certification and marketing in India

The country has recently begun to support organic agriculture on an outsized scale and at various levels. A national regulatory framework (standards, accreditation regulations) has already been passed in 2000. There are various schemes and events to support and facilitate exports of organic products (e.g., the massive conference 'Indian Organic Products -Global Markets' held in Delhi in December 2002, mainly sponsored by the Indian Government). The Ministry of Agriculture announced that various sorts of support for organic producers, processors, and traders were included within the newest five-year plan. The Ministry of Commerce has identified six organizations as accreditation agencies of organic products; they are as follows

1. Agricultural and Processed Food Products Export Development Authority (APEDA),
2. Tea Board of India (T.B.I.), Kolkata
3. Spices Board of India (S.B.I.), Kochi
4. Coconut Development Board (C.D.B.), Kochi
5. Directorate of Cashew and Cocoa Development (DCCD), Kochi
6. Coffee Board of India (C.B.I.), Bengaluru

These accreditation boards permit certifying agencies for certifying organic products, following the prescribed norms. Certification through these boards and agencies has been made compulsory, particularly for the export market, as 'the Government of India has issued a public notice consistent with which no organic products could also be exported unless they're certified by an inspection and certifying agency duly accredited by one 22 of the accreditation agencies designated by the Govt. of India' (Salvador and Katke, 2003). Several certifying agencies are functioning in India. Currently, around 12 states like Chhattisgarh, Tamil Nadu, Uttar Pradesh, Telangana, Sikkim, Bihar, Madhya Pradesh, Gujarat, Karnataka, Odisha, Rajasthan, and Uttarakhand have state organic certification agencies accredited by APEDA (Agricultural and Processed Food Products Export Development Authority). Some states have developed organic brands like Jaivik Jharkhand, Naga Organic, Nasik Organic, Bastar Naturals, MP Organic, Organic Rajasthan, Kerala Naturals, Organic Manipur, Organic Arunachal, Tripura Organic, etc. From 2016 to 2019, nearly 96 % of the entire certified organic food production was under NPOP certification, while the remaining 4 % was under the Participatory Guarantee System (PGS) of certification.

Reasons to Market Organic Farming

The earth's population has reached unprecedented levels, and providing food for the planet has become extremely difficult. Pollution and global climate change are the opposite negative externalities caused due to the utilization of fossil fuel-based chemicals like fertilizers, insecticides, and pesticides. Correspondingly, the necessity of the hour is sustainable cultivation and production of food. The clarification to require up organic farming includes:

» **To accrue the nutritional benefits :** Foods obtained from organic farming are loaded with nutrients like vitamins, enzymes, minerals, and other micro-nutrients compared to the food produced using conventional farms. This might be due to the management and nourishment of organic farms using sustainable practices. Previous researchers have concluded that food items from organic farms contained far more nutrients than those prepared from commercial or conventional farms.

» **To remain far away from G.M.O.s :** Studies reveal that genetically modified foods are contaminating natural food sources at a high pace and are manifesting severe effects. Further, they're not even labeled, which makes them an excellent threat. Accordingly, sticking to organic foods might be the sole thanks to mitigating the severe effects of G.M.O.s.

» **Natural and better taste :** Studies report that organically farmed foods have a genuine and better taste. The natural and superior taste results from the nourished and well-balanced soil. The organic farmer always prioritizes quality over quantity. The sugar content available in organically grown vegetables and fruits provides them with extra taste.

» Organic farming doesn't use poisonous chemicals, pesticides, and weedicides at any stage of the food-growing process like their commercial counterparts. Therefore, organic food does not contain any chemicals. These foods help to end diseases like cancer and diabetes etc.

» **Longer shelf-life :** Organic plants have more structural and metabolic integrity in their cellular structure than standard crops that enable more extended storage of organic foods. Organic farming is preferable because it battles weeds and pests in a non-toxic manner, involves fewer inputs for cultivation, and preserves the ecological balance while promoting biological diversity and protection of the environment.

Future Prospects of Organic Farming in India

India is an agriculture-based country with 67 % of its population and 55 % of human resources, counting on farming and related activities. Agriculture fulfills the essential needs of India's fastest-growing population accounted for 30 % of total income. Organic farming is an indigenous practice of India practiced in countless rural and farming communities over the millennium. The arrival of recent techniques and increased population burden led to a propensity towards conventional farming that involves the utilization of synthetic fertilizer, chemical pesticides, application of genetic modification techniques, etc.

Even in developing countries like India, the demand for organically grown produce is more as people are more aware now about the security and quality of food. Therefore the biological process features a massive influence on soil health, which is barren of chemical pesticides. Organic cultivation has an immense prospect of income generation, too (Bhardwaj and Dhiman, 2019). The soil in India is bestowed with various sorts of naturally available organic nutrient resources that aid in organic farming (Adolph and Butterworth, 2002; Reddy, 2010; Deshmukh and Babar, 2015). India may have a concrete traditional farming system, ingenious farmers, extensive drylands, and nominal use of chemical fertilizers and pesticides.

Moreover, adequate rainfall within the north-east hilly regions of the country where few negligible chemicals are employed for an extended period involves fruition as naturally organic lands (Gour, 2016). Indian traditional farmers possess a deep insight supported by their knowledge, extensive observation, perseverance, and practices for maintaining soil fertility and pest management, which are effective in strengthening organic production and subsequent economic process in India. The progress in organic agriculture is commendable. Currently, India has become the most important organic producer within the globe (Willer and Lernoud, 2017, 2019) and ranked eighth having 1.78 million ha of organic agriculture land within the world in 2017 (Sharma and Goyal, 2000; Adolph and Butterworth, 2002; Willer and Lernoud, 2019).

Various newer technologies are invented within the field of organic farming like integration of mycorrhizal fungi and nano biostimulants (to increase the agricultural productivity in an environmentally friendly manner), mapping cultivation areas more consciously through sensor technology and spatial geodata, 3D printers (to help the country's smallholder), production from side streams and waste alongside main commodities, promotion and improvement of sustainable agriculture through innovation in drip irrigation, precision agriculture, and agro-ecological practices.

Bee Scanning App is an advancement within the development of organic farming. Beekeepers can fight the Varroa destructor parasite mite and form a basis for population modeling and breeding programs (Nova-Institut GmbH, 2018). Inhana Rational Farming Technology developed on principle 'Element Energy Activation' may be a comprehensive organic method for ensuring ecologically and economically sustainable crop production, and it's supported ancient Indian philosophy and modern knowledge domain.

The technology works towards (1) energization of soil system: reactivation of soil-plant-microflora dynamics by restoration of the population and efficiency of the native soil microflora and (2) energization of plant system: restoration of the two defence mechanisms of the Plantae that are nutrient use efficiency and superior plant immunity against pest/disease infection (Barik and Sarkar, 2017).

Challenges to organic farming in India

» **Lack of awareness :** The foremost significant challenge within the development of Organic farming is the lack of awareness among farmers about organic farming and its potential benefits.

» **Marketing problems :** Before starting organic crop cultivation, their marketability over conventional produce must be assured. Inability to get a premium price for the produce, a minimum of during the nascent stages, results in a setback.

» **Shortage of biomass :** There might be a shortage of required quantities of nutrients which could simply not be enough to satisfy the necessities.

» **Inadequate infrastructure support :** Despite NPOP adoption, the state governments are yet to formulate a reputable mechanism and necessary policies for implementation. The certifying agencies are insufficient.

» **High input costs :** The prices of the organic inputs are quite high compared to those of industrially-produced agrochemicals utilized in the traditional farming system.

Needs to take efforts towards

» **Financial support** : Substantial support is important to market organic farming. In India, organic farming doesn't receive the advantages of state subsidies. A program for organic farming must be supported by total compensation both in cash and form to the farmers in a loss.

- **Market development :** It may be a crucial factor to endorse domestic sales. During this direction, a vital role of the Govt. should be supporting the producer and consumer associations to plug the products.
- **Awareness :** An active campaign is crucial to spotlight the advantages of organic farming against conventional farming and increase awareness among the farmers and consumers.
- **Crop identification :** Identification of crops for organic farming is vital.

Conclusion

Organic farming yields more nutritious and safe food. The recognition of organic food is growing dramatically as consumers seek organic foods that are thought to be healthier and safer. Thus, organic food perhaps ensures food safety from farm to plate. The organic farming process is more eco-friendly than conventional farming. Organic farming keeps soil healthy and maintains environmental integrity thereby, promoting the health of consumers. Moreover, the organic produce market is now the fastest-growing market everywhere in the globe, including India. Organic agriculture promotes the health of a nation's consumers, the ecological health of a nation, and therefore the economic process of a country by income generation holistically. At present, India is the world's largest organic producer (Willer and Lernoud, 2019), and with capacity building and greater awareness of the producers, organic farmers could soon be reinforcing their rightful place within the global agriculture trade. Due to the Covid Pandemic crisis within the world, the demand for safe and healthy food is showing high, and this is often an opportune moment for farmers to grow crops organically.

References

Adolph, B. and Butterworth, J. 2002. Soil fertility management in semi-arid India: its role in agricultural systems and the livelihoods of poor people. Natural Resources Institute, U.K.

Amit Khurana and Vineet Kumar. 2020. On a tardy trail: State of organic farming in India Area under organic cultivation is 2 % of the Net sown area in the country. Down to Earth, Blog, Agriculture, 08 September 2020, www.downtoearth.org.in/blog/agriculture/on-a-tardy-trail-state-of-organic-farming-in-india-73269.

APEDA, 2014. Agricultural and Processed food product Export Development Authority, Ministry of Commerce and Industries, G.O.I., www.apeda.gov.in.

Barik, A. and Sarkar, N. 2017. Organic Farming in India: Present Status, Challenges, and Technological Break Through. In: 3rd International Conference on Bio-resource and Stress Management, Jaipur, India.

Bhardwaj, M. and Dhiman, M. 2019. Growth and performance of organic farming in India: what could be the future prospects? *Journal of Current Science*, 20: 1–8.

Chandrashekar, H.M. 2010. Changing Scenario of organic farming in India: an overview. *International N.G.O. Journal*, 5: 34–39.

Chopra, A., Rao, N.C., Gupta, N. and Vashisth, S. 2013. Come sunshine or rain; organic foods always on tract: a futuristic perspective. *International Journal of Nutrition, Pharmacology Neurological Diseases,* 3: 202–205.

Deshmukh, M.S. and Babar, N. 2015. Present status and prospects of organic farming in India. *European Academic Research*, 3: 4271–4287.

Gour, M. 2016. Organic farming in India: status, issues and prospects. SOPAAN-II, 1: 26–36. Gutierrez, F., Arnaud, T., Albi, M.A. (1999). Influence of ecologic cultivation on virgin olive oil quality. *Journal of the American Oil Chemists' Society*, 76: 617–621.

Gupta A. and Verma J. 1997. Vanishing breeds, Down to Earth, 11(15): 27–37.

Guruswamy K. and Gurunathan K. B. 2010. A Need for Organic Farming in India. *Journal of contemporary research in management* January-march.

Indian Express. 2016. Sikkim became India's first fully organic state in 2016. December 31, 2016 10:26 am, Accessed on September 14, 2017.http://indianexpress.com/article/india/sikkim-became India's-first-fully-organic-state-in-2016-4452765/.

International Federation of Organic Agriculture Movements (IFOAM). 1998. The IFOAM basic standards for organic production and processing. General Assembly, Argentina, November, IFOAM, Germany. Organic Food Production Act of 1990 (U.S.C) s. 2103.

Makadia, J.J. and Patel, K.S. 2015. Prospects, status and marketing of organic products in India - A Review. *Agri. Review* 36(1): 73–76. DOI:10.5958/0976-0741.2015.00009.4.

Narayanan, S. 2005. Organic farming in India: Relevance, problems and constraints. Department of Economic Analysis and Research, National Bank for Agriculture and Rural Development. Mumbai.

Nova-Institute GmbH. 2018. High-tech strategies for small farmers and organic farming [press release]. http://news.bio-based.eu/high-tech-strategiesfor-small-farmers-and-organic-farming/.Accessed 28 April 2020.

Organic Foods Production Act of 1990. Pub. L. No. 101–624, §§ 2101-2123, 104 Stat. 3935 (codified at 7 U.S.C.6501–6522).

Reddy, S.B. 2010. Organic farming: status, issues, and prospects-a review. *Agricultural Economics Research Review*, 23: 343–358.

Salvador, V.G. and Katke, J. 2003. Market opportunities and challenges for Indian Organic Products Research Institute of Organic Agriculture (FIBL) and ACNielsen ORG MARG Swiss State Secretariat of Economic Affairs (SECO) http://orgprints.org/000026841.

Sharma, A. K and Goyal, R. K. 2000. Addition in tradition on agroforestry in an arid zone. LEISA-INDIA, 2: 19–20.

Shetty, P. K., Alvares, C. and Yadav, A. K. 2014. Organic Farming and Sustainability, ISBN: 978–93–83566–03–7, National Institute of Advanced Studies, Bangalore. 2014.

Sobhana, E., Chitraputhira Pillai, S., Swaminathan, V., Pandian, K., Sankarapandian, S. 2019. *Zero Budget Natural Farming*. doi:10.13140/RG.2.2.17084.46727.

Warnick, L. D., Crofton, L. M., Pelzer, K. D., Hawkins, M. J. 2001. Risk factors for clinical salmonellosis in Virginia, U.S.A. cattle herd. *Preventive Veterinary Medicine*, 49: 259–275.

Willer, H. and Lernoud, J. 2017. The World of Organic Agriculture, Statistics and Emerging Trends. FiBL & IFOAM-Organics International, Bonn.

Willer, H. and Lernoud, J. 2019. The World of Organic Agriculture.Statistics and Emerging Trends. Research Institute of Organic Agriculture (FiBL), Frick and IFOAM—Organics International,Bonn.https://www.organicworld.net/yearbook/yearbook-2019.html.

Winter, C.K. and Davis, S.F. 2006. Organic food. *Journal of Food Science,* 71: 117–124.

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