Chapter 5
Botanical Pesticides for an Eco-Friendly and Sustainable Agriculture: New Challenges and Prospects

Muzafar Riyaz, Pratheesh Mathew, S. M. Zuber, and Gulzar Ahmed Rather

Abstract The global food demand has been rapidly increasing due to expansion in the worldwide populace resulting in the waning of natural resources. The developed and emerging nations are tapping all means to feed the global population. In a run of these measures, many things brought ecological catastrophes and devastation to many organisms. In our farmlands, most of the crops are affected by a specific class of insects called pests. These pests are feeding on our crops, resulting in the collapsing of our agricultural produce. To save these crops from pests, we manufactured chemicals called pesticides which turned out to be very useful in eradicating the pests. Still, in the meantime, the excessive use of these pesticides brought massive devastation in many ways. Notably, most of the crops are dependent on cross-pollination, carried out by various types of insects. Around 80% of the crops worldwide are pollinated by insects (entomophily), especially the bees and other insect species of different families. But, with the frequent utilization of chemical pesticides, these pollinators and other beneficial insects are severely affected, resulting in a threat to their populations. The utilization of chemical pesticides affects insects, but their negative impact is also noticed in humans, aquatic organisms, birds, soil, water and the environment. So, the phytochemicals in botanical extracts are proven to be very much effective in preventing these dreadful crises due to a positive response by non-target organisms and low impact on our habitats and human health.

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5.1 Introduction

Since time immemorial, man has been cultivating and harvesting crops. Agriculture has consistently assumed a key position in boosting the economy of any country (Loizou et al., 2019). In the present world, agriculture is the chief fount of revenue in the nations engaged with agriculture and other farming sectors (Tang-Péronard et al., 2011). The upsurge in the global population has raised the alarm of food demand rising parallel to the worldwide population. The developed and emerging nations are tapping all means to feed the billions of people across the globe. In pest management practices, the advancement in technology has proven to be accompanying farmers to achieving higher amounts of crop yields. However, in our farmlands, most of the yields are being influenced by a particular class of insects called pests. These pests are feeding on our crops, resulting in the collapsing of most of our agricultural produce. The damage prompted to the crops by insect pests varies on the insect pests' feeding habit (Table 5.1).

Table 5.1 List of some common insect pests and their feeding habits

Common name	Order	Feeding habit
Aphids, mealybugs, whiteflies and scale insects (coccids)	Hemiptera	Plant sap
Hoppers	Hemiptera	Foliage and shoots
Caterpillars	Lepidoptera	Leaves and needles
Grasshoppers and locusts	Orthoptera	Leaves, grains, seed pods and fruits
Borers	Coleoptera, Lepidoptera	Roots, stem, shoots
Weevils	Coleoptera	Stored grains
Thrips	Thysanoptera	Fruit, leaves, shots, sap
Beetles	Coleoptera	Leaves, stem, petals, fruits
Pod bugs	Hemiptera	Seed pods
Stink bugs	Hemiptera	Leaves, fruits, stems, seed pods
Termites	Blattodea	Timber, furniture, branches
Cockroaches	Blattodea	Food, fabrics, fruits, books
Fruit flies	Diptera	Fruits, leaves
Gall midges	Diptera	Shoots, plant tissue
Saw flies, gall wasps	Hymenoptera	Plant foliage
Grubs	Coleoptera	Roots
Silverfish	Zygentoma	Books, clothes, food items

Though crops are affected by abiotic stresses, a significant portion of the crops and the harvest are influenced by the biotic stress of the insect pests. The insect pests can damage an entire or an enormous portion of our crop (Sharma et al., 2017). Around 70% of the crop can be lost to the pests if preventive measures are not taken since several species from different taxa include the natural insect predators and parasitoids that control the population of quite a few pest species. However, with the utilization of chemical pesticides, the natural enemies of the pests are becoming vulnerable. These chemical pesticides assume a significant position in agricultural and horticultural productivity (Carvalho, 2017). Pesticides have been assisting farmers by slashing the time and efforts to expel weeds and pests in farm fields for ages physically. However, due to the growing food demand, the utilization of chemical pesticides has risen enormously. Several environmental contaminations have also emerged with the considerable utilization of chemical pesticides. The soil, water and air quality got widely disrupted by the residues of these chemical pesticides. Life in aquatic ecosystems, beneficial insects and other vegetation became affected by the toxicity of these chemical pesticides (Riyaz et al., 2020).

Thus, to reduce the chemical pesticide contamination, carbon outputs, habitat destruction and fragmentation, sustainable agriculture is an effective alternative. Sustainable agricultural practices are way forward to maintain the ecological equilibrium by the eco-friendly techniques to reverse the damage done by large-scale agriculture and allied farming sectors (Slätmo et al., 2017). With a setup of a green environment and the cultivation of the crops, a lot of eco-friendly practices in sustainable farming can be utilized. These involve permaculture (Bhandari & Bista, 2019), aquaponics and hydroponics (AlShrouf, 2017), using renewable energy resources (Dudin, 2018), crop rotation and polycultures (Weißhuhn et al., 2017) and integrated pest management (Dara, 2019) (Fig. 5.1). With these practices, natural resource exploitation can be curbed. Further, diversification in the crops by crop rotation and polycultures can reduce fertilizers and pesticides. Chemical pesticides can be replaced by botanical pesticides, which are safer to handle and assure a low impact on the species of different taxa, their habitats, different ecosystems and human health (Nawaz, Juma, & Hongxia, 2016).

By introducing sustainable agricultural practices, the innovative technologies have progressed well to conserve the environment, beneficial insect diversity and human health. For eliminating the pests from farmlands, plant extracts are a creative and safe approach. The extracts can be obtained from dried or ground plant materials or crude plant. These plant extracts have been proven to be the best alternative to chemical pesticides as they can remove the pests from the farm fields while improving the quality of soil, water and air by their low impact. The plant extracts used as insecticides have a remarkable place among sustainable agriculture practices as they are safer than synthetic pesticides. In this chapter, sustainability of agriculture, botanical pesticides, their sources, usage, new challenges, prospects and effects of chemical pesticides on beneficial insect diversity, human health and aquatic ecosystems have been addressed in a detailed manner (Isman & Grieneisen, 2014).

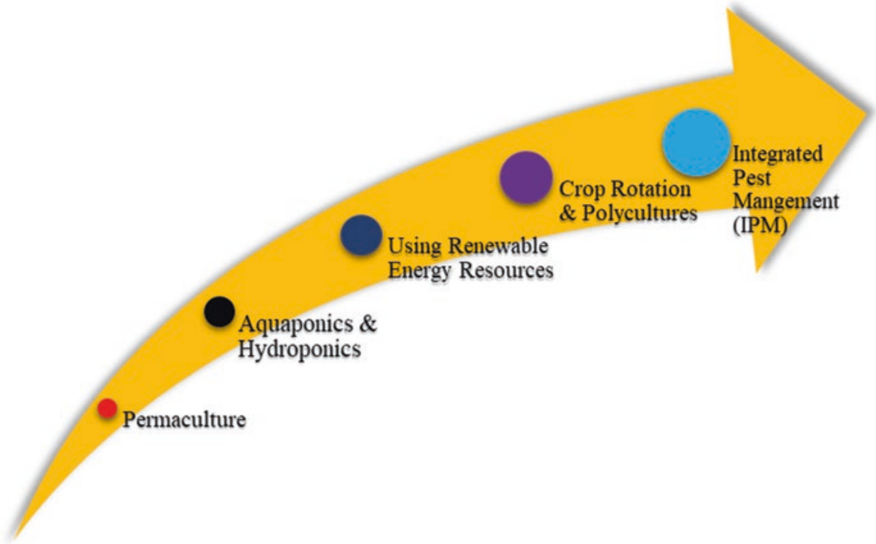

Fig. 5.1 Eco-friendly and sustainable agriculture practices

5.2 Sustainable Agriculture: A Promise to the Future

Back in the 1970s till now, there has been an enormous rise in environmental devastation brought about by the widespread agricultural activities (Majeed & Mazhar, 2019). Around 12% of the global greenhouse gas emissions are contributed by the activities such as industrial agriculture and other environmental devastations such as deforestation, habitat destruction, pesticide toxification and pollution, and intense carbon outputs caused the large-scale agribusinesses (Yue et al., 2017). Soil erosion can also be triggered by higher demands of agriculture on natural ecosystems (Nearing et al., 2017). There has been a rise in agricultural practices for a higher food demand as well, and for achieving a good result, the crops have been fertilized and sprayed with pesticides to save them from any pest damages. Safeguarding of these crops is only possible when we frequently splash them with pesticides, thereby achieving a good harvest. However, it has such severe implications on the environment and human health. For a good harvest to accomplish without menacing the soil, water, human wellbeing and the surrounding ecosystems, there is a need for eco-friendly and sustainable agriculture.

According to the Food and Agriculture Organization (FAO) of the United Nations, sustainability in agricultural development can be defined as 'the management and conservation of the natural resource base, and the orientation of technological change in such a manner, to ensure the attainment of continued satisfaction of human needs for present and future generations' (FAO, 2014). Sustainable farming becomes more substantial among the developed and developing nations

Fig. 5.2 The illustration shows the working of sustainable practices in agriculture

engaged in the agriculture sectors (Roberts & Mattoo, 2018). The deployment of sustainable agricultural practices into the farming sectors has proven to an innovative approach towards conserving natural resources like aquatic and terrestrial ecosystems, safeguarding the environment, human health and beneficial insect diversity, including pollinators and natural predators (Saunders, 2018). Sustainable agricultural practices aim to achieve higher crop yields, thus obtaining higher economic profitability (Fig. 5.2). With the advancement in technology, modern techniques can be employed in sustainable agriculture by which eco-friendly practices can be carried out so that there is the least wastage of harvest and natural resources. In sustainable agriculture, not only can we conserve our environment and natural resources but also train and exercise optimization of the usage of pesticides and fertilizers. The farmers implementing sustainable agriculture practices can achieve a higher crop yield and conserve their surrounding ecosystems contaminated by pesticide residues. Dealing with the pests in an agroecosystem and implementing integrated pest management (IPM) in sustainable agriculture are ways forward for dealing with the pests and eventually safeguarding human and environmental health. Integrated pest management (IPM) has emerged as the most ecosystem-based strategy for protecting crop and vegetable cultivations. With IPM, an aggregation of techniques can be employed such as biological, cultural, manual and chemical by implementing resistant varieties of crops and habitat management through which economic, health and environmental risk can be reduced (Peterson et al., 2018).

5.3 The Growing Pest Emergence, Problem and Utilization of Chemical Pesticides

The lower Devonian period marked the dawn of insect evolution. Because of their capability to withstand a wide range of climatic conditions, these species became the dominant creatures the planet has ever witnessed. The insects are the primary animals on the earth that adapted the flight capability, back around 400 million years ago, and dominated all the world's ecosystems (Riyaz et al., 2018). The flight ability provided immense support to the insect body for grabbing an edge over others and to get acclimatized in every nook and corner of the earth. The ability to flourish in different environmental conditions with flexible body parts helped these animals conquer even the limits of idiosyncratic environmental conditions. The arthropodic origin of insects and their power and life inside invertebrate phyla made them profoundly successful creatures of this planet. While insects flourished in the animal kingdom as dominating creatures, these creatures deliver several ecosystem services to the humankind and their world in a unique style. The pollens got shipped through cross-pollination by flying cargos of insects, and around 80% of crops across the globe are depending on the insects for transportation of their pollen from one flower to the other (McGregor, 1976). The insects have marked a natural establishment across all global ecosystems. Besides rendering the services like nutrient cycling, seed dispersal, fertility and structure of the soil, they are also proven to be a significant food source for other taxa. With all these characteristic roles they play in an ecosystem, a portion of insects turns out to be pests of many crops around the world. Saving the crop yield from the nuisances, there has been a progression in controlling these pests from time to time.

Along with the rise of agriculture in the ancient world, the eradication of the pests came on track back in 3000 BC, when ancient Egyptians employed trained cats and mongooses for controlling the pests of stored grains such as rodents and back in 500 AD in Europe when Ferrets were trained as mousers (Sherman, 2007; Taylor, 2011). Since it was simple to pulverize weeds in the farm fields by either blazing them or by tilling them out. However, with time and safeguarding crops, the ancient Sumerians utilized pesticides before 2000 BC (Pflanzenschutz-Nachrichten, 1973). Essential sulphur dusting was a conspicuously known pesticide and a key component utilized in ancient occasions around 4500 years back before Mesopotamia (Ranga Rao et al., 2007). Till the fifteenth century, toxic synthetic compounds, such as arsenic, mercury and lead, were sprinkled on yields for removing the nuisances. During the seventeenth century, nicotine sulphate from tobacco leaves was removed and utilized as a bug spray (Miller, 2002). With the disclosure of the insecticidal properties of DDT by Paul Muller in 1939, synthetic pesticides began to advance in the market. In 1948, he conceded the Nobel Prize to discover pesticide properties of DDT (Peshin et al., 2009). Eventually, in the 1960s, problems like the resistance of pests to chemicals, threat to biodiversity, aquatic and terrestrial ecosystems, climate and environment began to rise.

5.4 Erroneous Effects of Chemical Pesticides in Agriculture: Hazards to Human Health, Insect Biodiversity and Aquatic Ecosystem

'For the first time in the history of the world, every human being is now subjected to contact with dangerous chemicals, from the moment of conception until death' (Rachel Carson, 1962).

Pesticides are the chemical compounds developed for eliminating pests from agricultural fields, storage warehouses, homes, etc. Since time immemorial, man has been utilizing pesticides because their utilization has brought relief to farmers by expelling the pests from the farmlands. However, the large-scale usage of chemical pesticides has proven to be incompatible with the environment. Pesticides are generally used to remove insect pests (insecticides), fungi (fungicides), rodents (rodenticides), unwanted plants/weeds (herbicides/weedicides), nematodes (nematicides) and bacteria (bactericides) (Fig. 5.3). The impact of chemical pesticides on various life forms and different ecosystems has been reported across different world places. The nations engaged in different agricultural and allied sectors are mostly affected by it. With the rise in global population and food requirements, there has been a parallel growth in the large-scale cultivation of high-yielding monocrops. Since crop loss by the pests was controlled by the pesticides, their long-lasting adverse impact on various life forms and the natural environment is a significant challenge to be taken care of. On the contrary, the health of farmers has also declined due to their exposure to the toxicity levels of chemical pesticides. The chemical

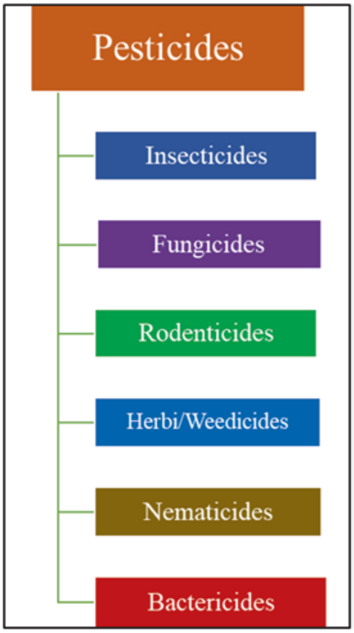

Fig. 5.3 Types of pesticides

Fig. 5.4 Pesticide sprayed in an apple orchid. (Photo Muzafar Riyaz)

pesticides have been most devastative on beneficial insect diversity, including pollinators such as honey bees, dipteran pollinators, predators, parasitoids and other useful insects that deliver several ecosystem services. In an agricultural field, several insects can be seen collecting nectar and pollinating the flowers, such as bees, wasps, hoverflies, moths and butterflies and some species checking the populations of insect pests such as parasitic wasps, hornets, beetles, lacewings, etc. While spraying the pesticides (Fig. 5.4) on crops infested with pests, 15 to 40% of an estimated fraction of pesticides are scattered into the atmosphere by either volatilization or spray drift processes (Socorro et al., 2016). After spraying, the pesticides in the atmospheric particulate phase remain in the air for about 7 to 12 days and thoroughly orbit many geographical locations worldwide. The circling of pesticides in the atmosphere alters the air quality and adds more events to climate change (Miller & Spoolman, 1996). The pesticide runoff from the agricultural lands into streams and lakes significantly impacts aquatic life and water contamination. Though runoff can transport pesticides into the aquatic ecosystem, the atmospheric dispersal of pesticides can travel to other places like grazing fields and human settlements, potentially affecting other living organisms and human wellbeing (Fig. 5.5). The impact of synthetic agrochemicals on insect diversity has been well documented

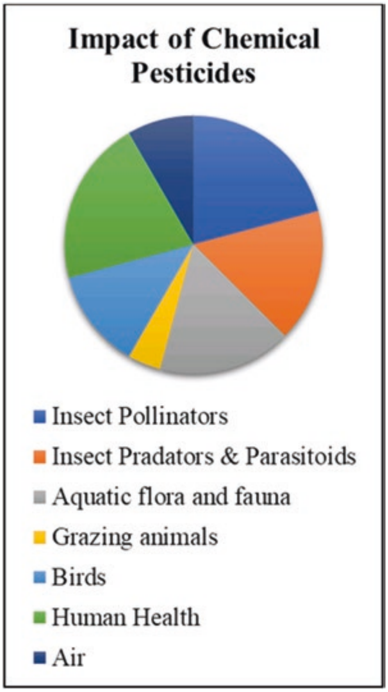

Fig. 5.5 The chart shows the impact of synthetic pesticides on different life forms

across the globe, and there has been a massive decline in insect pollinators from the past few decades due to the large-scale pesticide utilization (; Dudley & Alexander, 2017; Sánchez-Bayo & Wyckhuys, 2019). Some studies have shown that compounds of organophosphates and other pesticides can have poisonous or lethal effects resulting in the disruptions of cellular metabolism that often lead to embryonic changes and mutagenesis (Maurya et al., 2019) on fish species and birds (Tesfahunegny, 2016). Besides the impact of pesticides on the environment (Mahmood et al., 2016), soil (Joko et al., 2017) and water (de Souza et al., 2020; Hallberg, 1987), reports of pesticides influencing wildlife (Moriarty, 1972; Rattner, 2009), amphibians (Islam & Malik, 2018; McCoy & Peralta, 2018), earthworms (Yasmin & D'Souza, 2010), non-target plants (Mitra & Raghu, 1998; Saladin & Clément, 2005) and grazing animals (Choudhary et al., 2018) have also been well documented in the recent past (Fig. 5.6). Many studies worldwide have reported several health-related issues such as brain cancers, breast cancers, testis and ovarian cancers, leukaemias and lymphomas affecting people. A detailed list of health issues and diseases of humans caused by the exposure and poisoning of synthetic pesticides and their classification is given in Table 5.2.

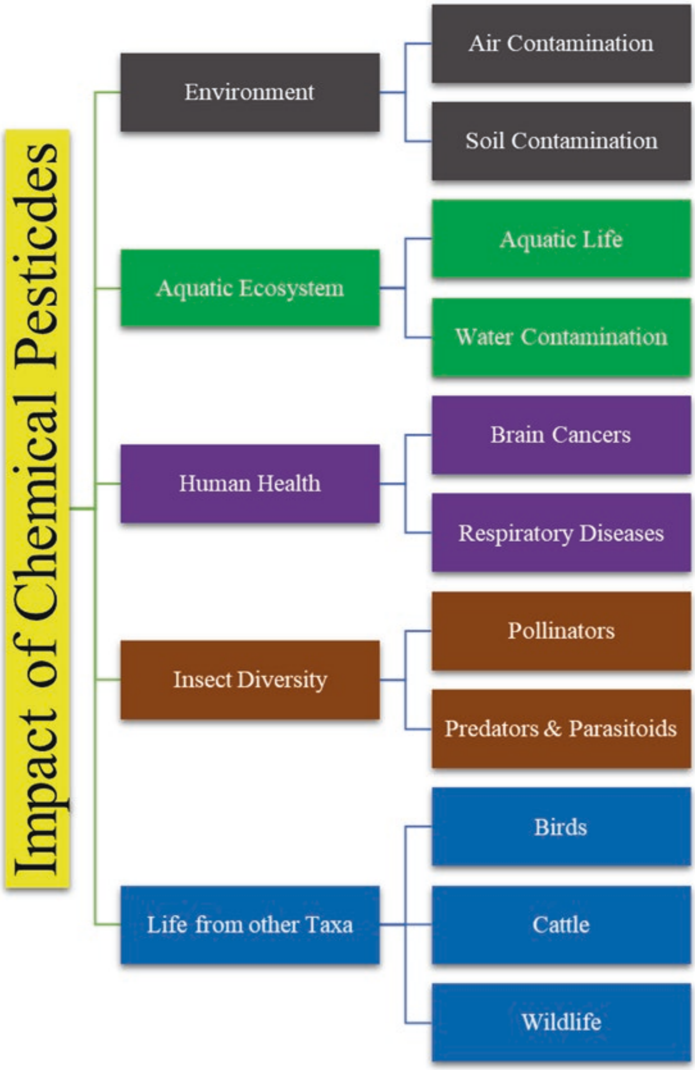

Fig. 5.6 The illustration shows the impact of synthetic pesticides on ecosystems, the environment and life from different taxa

5.5 Botanical Pesticides: A Natural Alternative for Chemical Pesticides

Synthetic pesticides are utilized as a swift remedy to the threat caused by pests in all stages of crop production (Ekeh et al., 2018). They include a wide range of chemicals that are non-biodegradable and persistent, polluting water, air and soil, leading

Table 5.2 Synthetic pesticides/insecticides: types and effects on human health

S. no.	Name (trade name)	Chemical formula	Antagonistic effects on human health	References
1	Chlorinated hydrocarbons			
2	Dichlorodiphenyltrichloroethane (DDT)	$C_{14}H_9Cl_5$	Cancer, nervous system disorders, respiratory damage, reproductive organs, immune system and endocrine disruptions, congenital disabilities	Thuy (2015); Cohn et al. (2015); Kim et al. (2017); Byard et al. (2015)
3	Methoxychlor	$C_6H_{15}Cl_3O_2$	Cancer, central nervous depression, diarrhoea, damage to the liver, kidney and heart	Chen (2014)
4	Dichlorodiphenyl ethanol	$C_{14}H_{12}Cl_2O$	Digestive tract infections, asthma, depression and morbidity, T-lymphocyte dysfunction, cancer, DNA damage	Igbinosa et al. (2013)
5	Chlorobenzilate	$C_{16}H_{14}Cl_2O_3$	Carcinogenic, genotoxic, eye damage	Lewis et al. (2016)
6	Benzene hexachloride (BHC) (lindane) (gamma-BHC or g-BHC)	$C_6H_6Cl_6$	Highly carcinogenic, dermatitis, psoriasis, burning, rashes	Loomis et al. (2015)
7	Toxaphene	$C_{10}H_{10}Cl_8$	Carcinogenic, immune system failure, reproductive organ damage, DNA damage	Wallace (2014)
8	Chlordane	$C_{10}H_6Cl_8$	Carcinogenic, type 2 diabetes, lymphoma, prostrate cancers, obesity, brain and breast cancer	Thakur and Pathania (2020); Evangelou et al. (2016); Lim et al. (2015); Tang-Péronard et al. (2011); Cook et al. (2011); Khanjani et al. (2007)

(continued)

Table 5.2 (continued)

S. no.	Name (trade name)	Chemical formula	Antagonistic effects on human health	References
9	Heptachlor	$C_{10}H_5Cl_2$	Hepatotoxicity, neurotoxicity and developmental toxicity, immune system damage, carcinogenic	Reed and Koshlukova (2014a), b)
10	Aldrin	$C_{12}H_8Cl_6$	Systemic, neurological, reproductive/ developmental, immunological, genotoxic and tumorigenic	US-EPA (2003)
11	Dieldrin	$C_{12}H_8Cl_6O$	Carcinogenic, neurological, reproductive/ developmental, immunological and genotoxic.	US-EPA (2003); Bates et al. (2008)
12	Endrin	$C_6H_8Cl_6O$	Central nervous system, headache, dizziness, nausea, vomiting, convulsions, fertility issues	Honeycutt and Jones (2014)
13	Chlordecone	$C_{10}Cl_{10}O$	Carcinogenic, body tremors, low sperm cell counts, recent memory loss, liver enlargement, oculomotor dysfunctions, ataxia	Multigner et al. (2016)
14	Endosulfan	$C_9H_6Cl_6O_2$ S	Cancer, acute and chronic toxicity, respiratory failure, endocrine disruption, reproductive failure, DNA damage	Singh et al. (2014); Sebastian and Raghavan (2016)
II	Organophosphates			
15	Tetraethyl pyrophosphate (TEPP)	C_8H_20 O_7P_2	Eye pain, blurred vision, lacrimation, rhinorrhoea	O'Neil et al. (2001)
16	Dichlorvos	$C_4H_7O_4Cl_2P_2$	Cancer, cell damage, neurotoxic, headache, sweating, nausea and vomiting	Koutros et al. (2008)

(continued)

Table 5.2 (continued)

S. no.	Name (trade name)	Chemical formula	Antagonistic effects on human health	References
17	Chlorfenvinphos	$C_{12}H_{14}O_4Cl_3P$	Developmental, reproductive and immunologic effects	Koshlukova and Reed (2014)
18	Phosphamidon	$C_{10}H_{19}O_5NClP$	Neurological disorders, cell damage	Naqvi and Hasan (1992)
19	Monocrotophos	$C_7H_{14}O_5NP$	Respiratory paresis, muscular weakness, cranial nerve palsies	Gupta and Milatovic (2014)
20	Dicrotophos	$C_8H_{16}O_5PN$	Blurred vision, pinpoint pupils, vomiting, headache, dizziness, abdominal pain, muscle spasms, diarrhoea, hypotension, respiratory paralysis	Pohanish (2015)
21	Trichlorfon	$C_4H_8Cl_3O_4P$	Nervous system disruption, nausea, respiratory paralysis, dizziness and sometimes death	Timoroğlu et al. (2014)
22	Methyl parathion	$C_8N_{10}NO_5PS$	Headaches, nausea, night-waking, diarrhoea, difficulty breathing, mental confusion, nervous system, cardiovascular and reproductive system	Edwards and Tchounwou (2005)
23	Fenthion	$C_{10}N_{15}O_3PS_2$	Neurotoxic, headache, sweating, nausea and vomiting, diarrhoea, muscle twitching and death	Moser (2014)
24	Diazinon	$C_{12}H_{21}N_2O_3PS$	Cancer, reproductive system, acute and chronic toxicity, respiratory failure, endocrine disruption	Beane Freeman et al. (2005); Harchegani et al. (2018)
25	Ethion	$C_9H_{22}O_4P_2S_4$	Clinical toxicity, abdominal pain, diarrhoea, vomiting, respiratory problems and undue secretions	Dewan et al. (2008)

(continued)

Table 5.2 (continued)

S. no.	Name (trade name)	Chemical formula	Antagonistic effects on human health	References
26	Phorate	$C_7H_{17}O_2PS_3$	DNA damage, nausea, dizziness, confusion, respiratory paralysis and death	Saquib et al. (2019)
27	Disulfoton	$C_8H_{19}O_2PS_3$	Nervous system disruption, respiratory disruptions, vomiting, diarrhoea, drooling, tremors, convulsions and sometimes even death	Fent (2014)
28	Dimethoate	$C_5H_{12}O_3PS_2N$	Cell damage, vomiting, abdominal pain, faecal incontinence, diarrhoea	Mirajkar (2014)
29	Malathion	$C_{10}H_{19}O_6PS_2$	Liver, kidney, testis, ovaries, lung, pancreas, blood, genotoxic and carcinogenic	Badr (2020)
III	Carbamates			
30	Carbaryl	$C_{12}H_{11}NO_2$	Neurological, reproductive, immunological disorders, possible carcinogen	Koshlukova and Reed (2014)
31	Aminocarb	$C_{11}H_{16}O_2N_2$	Cholinesterase inhibition, effects on the nervous system, sometimes death	Rodgers et al. (1986)
32	Carbofuran	$C_7H_{15}NO_3$	Body weakness, abdominal pain, blurred vision, nausea, sweating, muscle shuddering, coordination dysfunctions, respiratory and nervous system disorders	Gupta (1994)
33	Aldicarb	$C_7H_{14}N_2O_2$ S	Headache, nausea, sweating, diarrhoea, coordination system disruptions and sometimes death	Baron and Merriam (1988)

(continued)

Table 5.2 (continued)

S. no.	Name (trade name)	Chemical formula	Antagonistic effects on human health	References
IV	Pyrethroids			
34	Cypermethrin	$C_{22}H_{19}Cl_2NO_3$	Neurotoxic, hepatotoxic, effects on behaviour, molecular level and reproductive system	Sharma et al. (2018)
35	Deltamethrin	$C_{22}H_{19}Br_2NO_3$	Paranaesthesia, unwanted sensations, burning and partial numbness, 'pins and needles', skin problems	Doi et al. (2006)

to unintentional hazards to humans, non-target species and the environment, including depletion of the ozone layer (Damalas & Koutroubas, 2015; Lengai et al., 2020; Wimalawansa & Wimalawansa, 2014). Uncontrolled and continuous use of synthetic pesticides can also induce pesticide resistance among pest populations and pest resurgence, yet another disastrous factor in pest management (Shabana et al., 2017). These erroneous human health issues and drastic effects on nature and biodiversity invoked the thought for an alternative (Mahmood et al., 2016). Botanical extracts are biochemical compounds extracted from different plants, biodegradable with lesser shelf life, making them nature-friendly. Plant extracts were used in various fields by human life since time immemorial in many civilizations throughout the history in China, Egypt, Greece and India (Dougoud et al., 2019). The pesticide properties of botanical extracts have shown promising results, making them suitable candidates for integrated pest management (b; Ali et al., 2014; Isman, 2017a; Isman & Grieneisen, 2014; Mkenda et al., 2015; Stevenson et al., 2017). Due to their special attributes like lower toxicity, biodegradability, diverse modes of action, efficacy and obtainability of source materials, botanical pesticides are of greater importance from planting to harvesting and storing crops (Neeraj et al., 2017).

5.5.1 Source of Botanical Pesticides

Botanical pesticides are extracted from plant sources that can kill or control pests (Chengala & Singh, 2017). Every plant in nature has developed certain natural mechanisms in evolution to adapt to various environmental conditions with their pesticide property as one among them. A worldwide estimate of more than 2500 species of plants from 235 families has been noted to possess biochemical with pesticide or deterrent or growth-regulating properties (Das, 2014; Roy et al., 2016). Major plant families with active biomolecules against pests include Apiaceae, Apocynaceae, Asteraceae, Cupressaceae, Caesalpinaceae, Lamiaceae, Lauraceae, Liliaceae, Myrtaceae, Piperaceae, Poaceae, Rutaceae, Sapotaceae, Solanaceae, Zingiberaceae, etc. (Ahmad et al., 2017; Wanzala et al., 2016).

A wide range of common and locally available plants have also been reported to possess some pesticidal biochemical compounds like *A. indica* (neem), *Tanacetum cinerariifolium* (pyrethrum), *Allium sativum* (garlic), *Curcuma longa* (turmeric), *Rosmarinus officinalis* (rosemary), *Zingiber officinale* (ginger) and *Thymus vulgaris* (thyme) (Castillo-Sánchez, Jiménez-Osornio, Delgado-Herrera, Candelaria-Martínez, & Sandoval-Gío, Castillo-Sánchez et al., 2015). Compounds like azadirachtin from neem and pyrethrin from pyrethrum are common examples of isolated botanicals that have been commercialized due to their efficient results (Kumar et al., 2015). Selected examples of botanical pesticides against different pest groups are shown in Table 5.3.

The plant part used for extraction depends on the bioactive compound of interest and its concentration in a particular plant part, including root, rhizome, stem, bark, leaves, flower, fruit, seeds and cloves (Lengai et al., Lengai et al., 2020). The extraction and production of these botanical pesticides are economical and straightforward compared to synthetic pesticides, emitting large amounts of toxic pollutants as by-products or wastes. The process generally involves grinding of dried plant parts followed by extraction using organic solvents that maximize the extraction of target compounds (Chougule & Andoji, 2016). The extract is then concentrated, formulated and tested for evaluation in the lab and field trials (Zarubova et al., 2014).

5.5.2 Benefits of Botanical Pesticides over Synthetic Pesticides

The vast availability of source plants, diverse uses, less toxicity to non-specific targets like pollinators and fish, cheaper costs, effectiveness and reliability are the attributes responsible for the acceptability of the botanical pesticides in sustainable crop production (Castillo-Sánchez et al., 2015; Srijita, 2015). Botanical pesticides have been demonstrated to possess insecticidal properties even in their crude forms (Ali et al., 2014). Target specificity of compounds in plant extracts and essential oils ensures safeguarding non-target species and, more importantly, beneficial species like pollinators and natural predators (Nawaz, Mabubu, & Hua, 2016). The pesticide-pest interaction of botanical pesticides is biochemical, thereby decreasing the probability of pesticide resistance (Lengai et al., 2020). The efficacy of botanical pesticides can be influenced by parameters like a source of plant species, the raw material (fresh or dried) used for extraction, extraction methodology and solvents utilized for extraction (Arafat et al., 2015; Sarkar & Kshirsagar, 2014). Compared to synthetic pesticides, botanical pesticides show diverse modes of action like toxicity, repellence, growth regulation and structural modifications on target species, making them the best fit for integrated pest management (Laxmishree & Nandita, 2017). Botanical extracts, especially metabolites, can interfere with insect behaviour, morphology, metabolic pathways, biochemical processes and physiological

Table 5.3 Plants having pesticide effect on pests of different crops

Source plant	Pest	Host and disease/ damage	References
I	**Virus**		
Gossypium herbaceum	*Southern rice black streaked dwarf virus* *Tobacco mosaic virus* *Rice stripe virus*	Tobacco/tobacco mosaic Rice/leaf stripe infection	Zhao et al. (2015)
Thuja orientalis	*Watermelon mosaic virus*	Watermelon/WMV infection	Elbeshehy et al. (2015)
Cynanchum komarovii ***Celosia cristata***	*Tobacco mosaic virus*	Tobacco/TMV infection	Todorov et al. (2015)
II	**Bacteria**		
***Origanum* spp.**	*Bacillus* spp. *Serratia marcescens*	Wheat/white stripe Cucurbits/yellow wine disease	Jnaid et al. (2016); Sharoba et al. (2015)
Lantana camara	*Klebsiella pneumoniae* *Escherichia coli*		
Allium sativum	*Pseudomonas syringae*	Citrus/black pit	Mougou and Boughalleb-M'hamdi (2018)
III	**Fungi**		
Aloe vera ***Allium sativum*** ***Glycyrrhiza glabra***	*Fusarium guttiforme* *Chalara paradoxa*	Pineapple/ fusariosis	Sales et al. (2016)
A. indica ***Ocimum sanctum***	*Fusarium oxysporum*	Tomato/wilt	Chougule and Andoji (2016)
Allium sativum ***Curcuma longa*** ***Citrus limon*** ***Zingiber officinale***	*Bemisia tabaci* *Caliothrips fasciatus* *Uromyces appendiculatus* *Phaeoisariopsis griseola* *Colletotrichum lindemuthianum*	Snap bean/whitefly damage Snap bean/thrips damage Snap bean/rust Snap bean/angular leaf spot Snap bean/ anthracnose	Muthomi et al. (2017)
Hydnocarpus anthelminthicus	*Phytophthora palmivora* *Pyricularia oryzae* *Rhizoctonia solani*	Rice/fungal infection	Jantasorn et al. (2016)
IV	**Nematode**		
A. indica ***Brassica napus*** ***Lantana camara*** ***Tagetes erecta***	*Meloidogyne incognita*	Tomato/root knot	Kepenekçi and Erdo (2016)
Tagetes erecta ***Chromolaena odorata***	*Meloidogyne incognita* *Helicotylenchus* spp. *Dolichodorus* spp.	*Amaranthus* Fluted pumpkin	Ogundele et al. (2016)

Table 5.3 (continued)

Source plant	Pest	Host and disease/damage	References
Thymus citriodorus	*Meloidogyne incognita* *Meloidogyne javanica*	Tomato/root knot	Ntalli et al. (2020)
V	**Insect**		
Cinnamomum cassia ***Cinnamomum zeylanicum*** ***Piper nigrum***	*Megalurothrips sjostedti*	Cabbage/flower damage	Abtew et al. (2015)
Aglaia odorata ***Annona squamosa*** ***Piper retrofractum***	*Crocidolomia pavonana* *Plutella xylostella*	Cabbage/foliar damage	Abtew et al. (2015)
Allium cepa ***A. sativum*** ***A. indica*** ***Curcuma zedoaria*** ***Calotropis procera*** ***Ocimum canum*** ***Phyllanthus emblica***	*Helicoverpa armigera*	Tomato/fruit damage	Sumitra et al. (2014)

activities; blocking of glucose in chemosensory receptor cells in the mouth of lepidopterans by terpenes and chemosterilant activity of some essential oils are a few examples (Lengai et al., 2020).

Utilization of botanical pesticides in pest control guarantees added benefits to farmers like food security, lowering pest intensities and enhanced superiority of harvest, drawing greater demands and higher rates in the market (Nefzi et al., 2016). Organically produced food products are in greater demand in the lucrative market, where consumers are ready to buy these foods at higher rates creating greater market openings for botanical pesticides (Misra, 2014).

5.5.3 Biodegradability of Botanical Pesticides

The botanical pesticides are quickly degraded, with their biological origin preventing their accumulation in the environment and thereby eliminating the chances of air, water and soil pollution (Sokovi' c, 2010). Exposure to sunlight, high temperature and humidity could break down their constituents depending on their nature, e.g. azadirachtin, isolated from neem (*A. indica*), has a half-life between 1 day over crops and 2 days in soil, whereas thymol, a compound extracted from *Piper nigrum*, *Satureja hortensis*, *Thymus vulgaris* and *Zataria multiflora* under sunlight, is proved to survive up to 28 hours to degrade and in soil with a duration of 8 days (Liu et al., 2017; Yan et al., 2017; Yang et al., 2017). The biodegradation process is accelerated by detoxification enzymes secreted by microorganisms present in abundance in natural conditions through oxidative metabolism (Mpumi et al., 2016).

Carboxylesterase enzyme-mediated hydrolysis of ester bonds is a common pathway of biodegradation exhibited by microorganisms such as *Bacillus cereus* and *Aspergillus niger* (Cycoń & Piotrowska-Seget, 2016). A wide variety of bacterial species are reported to degrade carbamates, organophosphates, organochlorine pesticides and pyrethroids (Cycoń & Piotrowska-Seget, 2016; Porto et al., 2011).

In soil, enzymes produced by microorganisms modify the botanical pesticides into less toxic groups that are breakable, rendering them biologically unavailable and making them non-toxic (Ortiz-Hernández et al., 2013). Microbial degradation is further influenced by physical factors and interaction with pesticides and environmental conditions (Cycoń & Piotrowska-Seget, 2016).

5.5.4 Botanical Pesticides for Integrated Pest Management

Integrated pest management (IPM) aims to achieve sustainable pest management through environment-friendly strategies for reducing pests and attaining highly profitable yields (Alam et al., 2016). Botanical pesticides are eco-friendly natural compounds effective against different pests like viruses, bacteria, fungi, nematodes and insects with varied modes of action (Feyisa et al., 2015; Todorov et al., 2015). Alongside crop, security approaches like host plant resistance or tolerance, the introduction of natural enemies like parasitoids and predators, improved agricultural practices, use of microbial pesticides and reduced use of chemical pesticides, application of botanical pesticides also serve as a critical component in IPM (Muthomi et al., 2017; Wegulo et al., 2015). Compounds extracted from plant sources are effective against a major group of pests like viruses, bacteria, fungi, nematodes and insects (Elbeshehy et al., 2015; Ingle et al., 2017; Neeraj et al., 2017; Sales et al., 2016; Salhi et al., 2017). This wide variety of botanical pesticides and their results using crude form, extractions and formulations opens a wide scope for complete replacement of synthetic pesticide with these eco-friendly pesticides, which immensely contributes to integrated pest management and sustainable agriculture for a healthy future (Fig. 5.7).

5.6 Prospects of Botanical Pesticides: Discussion and Conclusion

The large-scale utilization of chemical pesticides has affected the pollinators and other beneficial insects, but its negative impacts have also been noticed on human health, aquatic organisms, birds, wildlife, grazing animals, earthworms, soil, air, water and the environment. The phytochemicals in botanical extracts are proven to be much effective in preventing these dreadful crises due to a positive response by non-target organisms and low impact on the environment and human health. Even

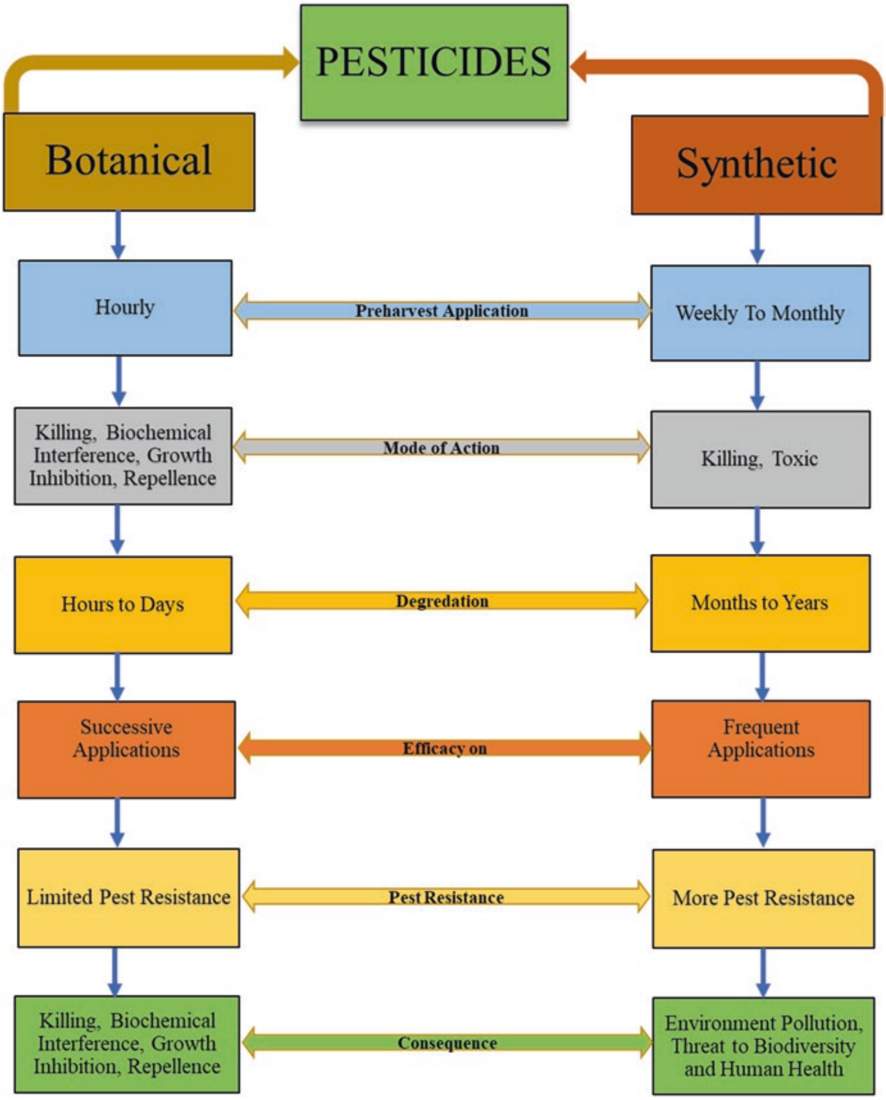

Fig. 5.7 An illustration comparing synthetic and botanical pesticides based on different parameters

with great scope, botanical pesticides are not much represented in the pesticide market (Kekuda et al., 2016). Plants that are being used for food are less preferred for pesticide production by farmers due to a greater demand for food security (Srijita, 2015). Farmers have shown interest in synthetic pesticides over botanicals due to their unrestricted availability and established production facilities, leading to cheaper rates in the market, longer shelf life and simpler application methods (Lengai et al., 2020). Little awareness among farmers, complex regulatory procedures for production, chances of biodegradability with physical factors, reported rare side effects on non-target species, dependency on extraction methodology for promising results, etc. diminish the presence of botanical pesticides in agricultural fields, which needs to be addressed with comprehensive future research (Ekpo et al., 2017; Okunlola & Akinrinnola, 2014; Sales et al., 2016; Stevenson & Belmain, 2017).

In light of these facts, the governments by implementing agricultural laws utilizing natural pesticides in economic ways for farmers could bring around eco-friendly farming practices. Considering the drastic effects of synthetic pesticides and the benefits of botanical pesticides, it is an environmental emergency to replace synthetic pesticides with botanicals and other organic pesticides. With technological advancements and the exploration of more plants with pesticide effects, botanical pesticides could eventually replace synthetic pesticides for safer, environment-friendly and sustainable agriculture soon. This could also bring about the use of these plants and plant products as a source of income for many societies, especially the rural and tribal, which will direct towards eradicating unemployment and sustainable utilization of available natural resources contributing to the development of the country and humanity.

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