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Chapter 10

Applications of Plant Extracts in Pest Control

Sushruta Boruah[1*], Mahesh Pathak[2], Ramya A.R.[1], Bimal Kumar Sahoo[1], Kasturi Sarmah[1], Mohammad Ikram[1] and Mukesh Sehgal[3]

[1]*Dept. of Agricultural Entomology, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu (641 003), India*
[2]*Dept. of Entomology, School of Crop Protection, College of Post Graduate Studies in Agricultural Sciences, Central Agricultural University (Imphal), Umiam, Meghalaya (793 103), India*
[3]*ICAR-National Centre for Integrated Pest Management (NCIPM), Pusa Campus, New Delhi (110 012), India*

Abstract

Pest management faces significant monetary and environmental constrains globally owing to the extensive usage and more dependency on synthetic pesticides. These chemicals pose serious concerns because of their non-target toxicity, residual effects and difficulty in biodegradation, necessitating the urgent implementation of sustainable and profitable pest management methods. The growing focus on environment friendly has spurred awareness in eco-friendly plant-based insect control techniques. Plant based pesticides have been effective against numerous pests and diseases, commonly available, low-priced, easily decomposable and exhibit low toxicity to beneficial organisms. Their efficacy is attributed to the phytochemical compositions in various plants, which provide diverse mechanisms of action against insect pests and diseases. Despite their potential, the adoption of botanical pesticides has been limited due to formulation difficulties and insufficient chemical data. The rising call for food to support the rising population initially directed to the dependence on synthetic pesticides for quick insect and disease management. However, the adverse impacts on human health, the surroundings and the emergence of resistant pest strains have driven the quest for substitute methods, with botanical pesticides attaining momentum. The varied modes of action of plant-based pesticides, stemming from their phytochemical composition, make them suitable for inclusion in integrated pest management systems, thereby contributing to sustainable agricultural system.

Keywords Biodegradation, Botanical pesticides, Pest management, Sustainable agriculture, Synthetic pesticides

[*]***Corresponding author's e-mail***: sushrutaboruah277@gmail.com

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1. Introduction

During the Green Revolution in the 1950s and 1960s, crop cultivation increased to meet food demands in low-income countries with the substantial use of inputs such as inorganic fertilizers, chemical pesticides and genetically modified organisms (Kumar and Singh, 2014). As agricultural crops are at higher risk due to attack of pests, so in order to safeguard crops, farmers often rely on synthetic chemicals for quick pest control (Nkechi *et al.*, 2018). While effective, the continuous use of chemical insecticides has led to threats such as the development of pesticide-resistant pests (Shabana *et al.*, 2017). The overuse and misuse of these chemicals result in harmful effects on humans and the environment, including toxicity to non-target organisms, which negatively impacts biodiversity (Damalas *et al.*, 2016). The compounds in synthetic pesticides are linked to chronic human ailments through consumption or exposure (Dhanavade *et al.*, 2011). Additionally, most synthetic pesticides are not easily biodegradable, leading to environmental pollution and ozone layer depletion (Sande *et al.*, 2011). These disadvantages have stirred the need for alternative pest management options (Mahmood *et al.*, 2016).

Plant-derived pesticides, used for millennia before synthetic pesticides, are naturally occurring plant by-products that deter, attract or obstruct pests (Hikal *et al.*, 2017). Historically, plants possessing biologically active ingredients have been successfully utilized to control crop pests and human diseases (Thiruppathi *et al.*, 2010). Many plants, such as pyrethrum, tobacco, neem, sabadilla and ryania, have been identified as sources of effective botanical pesticides (Shabana *et al.*, 2017). These plant-derived pesticides manage insect pests and plant pathogens like nematodes, fungi, bacteria and viruses (Waziri, 2015). They offer positive environmental impacts, low mammalian toxicity and low resistance risk, which makes them fit for integrated pest management (Liu Xing *et al.,* 2017). However, with the advent of synthetic pesticides, their use declined due to the immediate effectiveness of synthetic chemicals in managing severe crop diseases (Raja, 2014). Nonetheless, recent concerns over the negative impacts of chemical pesticides on community health and safety of surroundings have revived interest in plant-based pest control methods (Mohammad and Najafi, 2016). The global trend now favors food production with the use of non-toxic, natural plant safety substances. Dangerous chemical deposits in foods and augmented consumer alertness of food safety have led to bans on specific chemicals used in agriculture, boosting the popularity of plant-based pesticides in organic farming (Karaca *et al.*, 2017). Constant usage of chemical pesticides has caused contamination, health threats and loss of biodiversity, while adopting plant-based pesticides fosters a healthy environment and sustainable agriculture (Shabana *et al.*, 2017). The misuse of chemical pesticides has adversely impacted farming community in export trade, specifically horticultural yield, where banned pesticide residues lead to market and income losses (NAShwA and Abo-ElyouSr, 2012). The growing significance of plant-based pesticides is credited to their effectiveness, biodegradability, diverse mechanisms of action, low toxicity and accessibility (Neeraj *et al.*, 2017). They also have small pre-harvest and re-entry intervals, making them popular in organic farming where premium prices are f*etc*hed for organically produced food (Gupta and Diksit, 2010). Consequently, botanical pesticides are gaining traction as safe options for crops intended for human consumption, catering to a profitable market of customers eager to pay extra for organic produce (Mizubuti *et al.*, 2007). In spite of the rise of synthetic pesticides, the negative impacts on human health and the surroundings have rekindled interest in botanical alternatives (Nikkhah *et al.*, 2017). These botanical pesticides are now popular in organic farming due to their safety and effectiveness. This chapter deliberates the significance of plant-derived pesticides in sustainable pest management, conveying information on their phytochemical composition, mode of action and the contrains hindering their broader acceptance and application.

2. Global Status of Botanical Pesticides

New pesticides, including botanicals, are being discovered and developed to replace active compounds that are no longer viable due to updated registration requirements. Botanical products have a long history as crop protectants, with numerous plant-derived compounds such as essential oils, terpenoids, lipids, sterols, alkaloids, flavanones and polypeptides being identified and registered as biopesticides. Plants provide a rich source of bioactive compounds that play crucial roles in their interactions with the environment (Ngegba *et al.*, 2022). Globally, approximately 2,500 species from 235 plant families have proven effective in pest control. Phytochemicals are of interest for managing plant diseases because they are species-specific, often have unique modes of action, exhibit low toxicity to humans and degrade quickly into non-toxic substances under environmental conditions (Dang *et al.*, 2012).

Sustainable agriculture is the way to feed the world compounds present in the essential oils can be classified into two chemical groups, according to their metabolic synthesis pathways: (i) low molecular weight phenylpropanoids and (ii) terpenoids (monoterpenes and sesquiterpenes). Monoterpenes are synthesized in the plastids *via* the methylerythritol phosphate pathway, while sesquiterpenes are synthesized in the cytosol *via* the mevalonate pathway (Campos *et al.*, 2019).

New active compounds, including botanicals, are being more and more investigated and developed to replace older pesticides that no longer meet updated regulatory requirements. Traditional botanical products have been used for a very long time in crop protection, with the identification and registration of a very large number of plant-derived biopesticides, such as essential oils, terpenoids, lipids, sterols, alkaloids, flavanones and polyketides. Plants constitute a useful source of bioactive compounds that play an essential role in interaction with the environment (Ngegba *et al.*, 2022). Almost 2,500 species from 235 families of plants have been reported for their usefulness in pest management from different parts of the world. Of particular interest in plant disease control, phytochemicals are species-specific activities, novel modes of action, very low mammalian toxicities and rapid degradation into non-toxic residues in the environment (Dang *et al.*, 2012). In the context of sustainable agriculture, the chemical compounds present in essential oils could be divided into two main chemical groups, according to their metabolic synthesis pathways: i) low molecular weight phenylpropanoids and ii) terpenoids, including monoterpenes and sesquiterpenes. Whereas monoterpenes are synthesized in the plastids *via* the methylerythritol phosphate pathway, sesquiterpenes are synthesized in the cytosol by the mevalonate pathway (Campos *et al.*, 2019).

Though Brazil, China and India are the largest producers of research on botanical insecticides, major differences do exist among these nations in the regulation of botanical pesticides (Turchen *et al.*, 2020). Although Brazil's Ministry of Agriculture has, for many years now, encouraged and endorsed the use of local plant extracts and oils, such as pyrethrum and neem, Brazil still had one of the toughest pesticide regulatory frameworks in the world up until 2019, with required approval by three independent government agencies. Recently, moves to cut through the red tape in Brazil could herald easier passage for botanicals and other low-risk pesticides. In contrast, India has recently increased its approved list to 11 botanical pesticides, representing various plant oils and extracts, but most specifically neem- and azadirachtin-based products. This might be expected with neem native to India, having been introduced to other tropical and subtropical regions. Meanwhile, China also emerges as one of the main leaders in the development and commercialization of botanical insecticides, including the products that contain active ingredients derived from plants such as Sophora and Veratrum (Isman, 2020) In India, only three plant-derived pesticides, Azadirachtin, Pyrethrum and Eucalyptus foliar extract, have been registered for commercial use. Among these, neem-based products are the most extensively used compounds in farming, followed by Pyrethrum and Eucalyptus leaf extract (Shivkumara *et al.*, 2019).

3. Applications of Botanical Pesticides

Numerous plant-derived pesticides have been explored, yet a substantial number remain to be seperated and analyzed to recognize their bioactive constituents. These abundant botanical foundations have been underused and ignored as pesticidal substances for managing a wide range of notorious insects and pathogens. Various studies have been conducted on the use and effectiveness of botanicals as alternate pest management strategies in sustainable agriculture and linked fields. These products serve as insect repellents, antifeedants, insecticides and insect growth inhibitors. Additionally, plant-derived biologically active compounds are used as nematicides, fungicides, bactericides and virucides. Numerous plants possess pesticidal probability, extensive research has been conducted and various effectiveness has been established.

3.1. Insecticidal Activities

Pesticides based on plant extracts such as *Azadirachta indica*, *Allium sativum*, *Chrysanthemum cinerariaefolium*, *Datura metel*, *Hyptissu aveolens*, *Lantana camara*, *Mirabilis jalapa*, *Ryania speciosa* and *Tagetes minuta* are employed to control common bean pests, which includes aphid, armyworm, bean leaf spot, bollworm, cabbage looper, grasshopper, bruchid beetle, pink stalk borer and thrips (Karani *et al.*, 2017). Extractions from *Carica papaya* and *T. minuta* were particularly potent in decreasing aphid populations and leaf injury owing to their diverse insecticidal constituents (Murovhi *et al.*, 2020). *C. papaya* leaf extracts comprises of cysteine protease enzymes like papain, along with alkaloids, terpenoids, flavonoids and non-protein amino acids which are toxic to aphids, spotted bollworms, whiteflies *etc.* (Ahmad *et al.*, 2018). *T. minuta* leaf extracts have phenylpropanoids, carotenoids, flavonoids, phototoxin alpha-terthienyl and thiophenes, which effectively control insect pests (Dunkel *et al.*, 2018). Azadirachtin, a compound from *A. indica*, has multiple modes of action including antifeedancy, morphological damage, biological fitness alteration, fecundity suppression and growth inhibition (Zhang *et al.*, 2018). It adversely affects pupation in insects like *Drosophila melanogaster*, *Spodoptera frugiperda* and *Callosobruchus maculatus* and has a significant anti-lepidopteran effect, especially from neem bark extracts due to higher azadirachtin and nimbin contents (Lai *et al.*, 2014). Neem oil concentrations increased mortality and caused morphological deformities in insect appendages (Zanuncio *et al.*, 2016). Extractions from *A. indica*, *Ocimum sanctum* and *Eucalyptus globulus* showed noteworthy insecticidal property against *Aphis gossypii* and *Phenacoccus solenopsis* in laboratory conditions (Singh *et al.*, 2012). Moreover, neem leaf extract significantly decreased the fecundity and persistence rates of adults of grain/seed storage pests at a concentration of 1.5 mg/ 100 g (Ahmad *et al.*, 2015). Organic fertilizers enriched with neem leaf powder and boiler ash significantly improved plant resistance against aphids (Brotodjojo *et al.*, 2016). Azadirachtin caused lethal toxicity in pupa, triggering substantial morphological damages and delaying adult development in *D. melanogaster* (Boulahbel *et al.*, 2015). Azadirachtin is also found to cause deformity in larvae, pupae and adults, reduced protein synthesis in pupae, low hemolymph bulk during the late instar larvae, inhibited enzyme functions in larvae gut and lowered cuticular protein levels in larvae of *Spodoptera litura* (Yooboon *et al.*, 2015). Azadirachtin interrupted juvenile hormone and 20-hydroxyecdysone pathways, leading to incomplete growth of larvae, sterile eggs and reduced egg laying capacity (Abedi *et al.*, 2014).

3.2. Fungi Management

Extractions from numerous species of plants have been found effective against various plant pathogens without causing adverse aftermath effects. These plants based bioactive molecules, which includes alcohols, alkaloids, phenols, tannins and terpenes, not only inhibit germ tube extension and growth of mycelia but also suspend spore formulation, DNA and protein formation (Lengai *et al.*, 2018). They alter the structure of hyphae and mycelia and inhibit the synthesis of toxic compounds from toxin-producing fungi such as *Aspergillus* spp. and *Fusarium* spp., thereby dropping their infectiveness (Martnez *et al.*, 2012). Reports indicated that turmeric essential oil and curcumin were effective against plant pathogens-bacteria and fungi (Sivaranjani *et al.*, 2016). Alcoholic extractions from suicide tree (*Cerbera odollam*), clove (*Syzygium aromaticum*) and mahogany (*Swieteniam acrophylla*) at 3000 ppm inhibited the growing of *A. niger*, *Penicillium digitatum* and *Fusarium* spp. by 40-90% in citrus. Extraction from ginger decreased the cytoplasm and altered the microconidia morphology of *Fusarium* spp. (Yamamoto-Ribeiro *et al.*, 2013).

3.3. Bacteria Management

Botanical compositions exhibit diverse antibacterial properties, offering promising alternatives for managing bacterial infections in crops. Research has shown that acetone extraction of *Aloe vera* effectively impacted the growing of *Pseudomonas aeruginosa*, whereas the methanolic extracts repressed *Escherichia coli* and *Bacillus subtilis*. The disinfectant activity of *Aloe vera* is accredited to its chemicals which denature microbial proteins and disturb their functions, such as cinnamic acid that inhibits glucose uptake and ATP production (Djeussi *et al.*, 2013). Some botanical pesticides disrupt bacterial cellular enroutes and upsurge membrane permeability, leading to cell content leak and death (Khan *et al.*, 2009). Essential oils of *Thymus vulgaris*, containing thymol, enhance membrane permeability and cause depolarization, which interferes with the cellular machineries of *Bacillus cereus*, *Klebsiella pneumoniae*, *Staphylococcus aureus*, *Salmonella typhimurium* and *E. coli* (Plant *et al.*, 2015). *Datura metel* significantly decreased the growing of *Xanthomonas oryzae* pv. *oryzae in vitro* and decreased bacterial leaf blight in rice, primarily due to the presence of daturilin (Sateesh *et al.,* 2004). Various plant extracts, including *D. metel*, *Azadirachta indica*, *Ipomoea cornea*, *Vitex negunda* and *Ziziphus jujuba*, also showed antibacterial characteristics against *Xanthomonas campestris* pv. *Oryzae* (Sateesh *et al.*, 2004). In protected cultivations and field experiments, aqueous extracts of *Hibiscus sabdariffa*, *Punica granatum* and *Eucalyptus globulus* successfully protected potato plants from bacterial wilt caused by *R. solanacearum*. *In vitro* studies also confirmed that *A. sativum* extracts decreased *R. solanacearum* populations in soil (Abo-Elyousr *et al.*, 2009).

3.4. Nematodes Management

Essential oils from pesticidal plants have been effective in managing root-knot nematodes (*Heterodera cajani*), influencing mortality in second-stage juveniles (Singh *et al.*, 2001). Lipophilic phytochemicals, which can disrupt nematode cytoplasmic membranes, hinder protein structures crucial for nematode growth, development and persistence (Pavaraj *et al.*, 2012). Growers have used crushed leaves of African marigolds to manage nematodes and certain plant elements affect soil microbial populations, reducing nematode egg production and larval survivability (Khan *et al.*, 2008). Compounds that cause second-stage larval mortality and reduce egg masses and galling have been noted for their suppressive effects on nematode populations (Kepenekçi *et al.*, 2016). Under laboratory environment, extracts of *Lantana camara* and *Trichoderma harzianum* inhibited root-knot nematode proliferation, egg masses and gall development in tomatoes. Bioactive complexes for instance alkaloids, tannins and glycosides are associated with decreased egg hatching, reduced mobility and mortality of second-stage juveniles (Akyazi *et al.*, 2014). Pesticidal plant extract can causes paralysis and bounds the infection of juvenile root-knot nematodes (Oka *et al.*, 2012).

3.5. Viruses Management

Certain plant compounds encourage systemic resistance in plants with anti-viral characteristics by preventing virus spread and killing arthropod vectors (Waziri, 2015). These compounds can hinder virus entry, multiplication, hemagglutination and enzyme action (Rajasekaran *et al.*, 2013). For instance, certain compounds from *Tamarix orientalis* suppressed the proliferation of Watermelon Mosaic Virus by reducing virus infection in hypocotyls. At a concentration of 5-6 g L^{-1}, extracts from *T. orientalis* and *Artemisia campestris* repressed Potato Leafroll Virus proliferation by over 80% and 60%, respectively (Al-Ani *et al.*, 2010). *Paronychia argentea* extracts at about 10 g mL^{-1} applied as a foliar spray 24 hours before viral inoculation reduced disease symptoms, improved plant development and reduced TMV build-up in treated tomato plants (Abdelkhalek *et al.*, 2021). Plant extracts from *Eucalyptus camaldulensis*, *Clerodendrum aculeatum*, *Haplophyllum tuberculatum*, *Mirabilis jalapa*, *Potentilla arguta*, *Boerha aviadiffusa*, *Sambucus racemosa* and *T. orientalis* have been found to prevent plant virus contaminations (Abdelkhalek *et al.*, 2020). Field trials have demonstrated that extracts from *Azadirachta indica*, *Plectranthu stenuiflorus*, *Schinustere binthifolius* and *Clerodendrum inerme* can induce resistance against Bean Common Mosaic Virus (BCMV) (El-Sawy *et al.*, 2017). Extracts from *Thuja*, *Tamarix* and *Henna* have repressed Tomato yellow leaf curl virus spread, providing above 10 days of shield in tomato plants (Al-Aniet *et al.*, 2011).

4. Advantages of Botanical Pesticides over Synthetic Pesticides

The harmful impact of chemical insecticides on human health comprises of bioaccumulation of pollutants within food chains, which spread across land-dwelling and water ecosystems. Common chemical insecticides such as Dichloro diphenyl trichloro ethane (DDT) and toxaphene can leave long lasting influence in the soil that last for decades, with the potential to leach into ground water and affect water life. The World Health Organization estimates that pesticide exposure leads to approximately 2 lakhs deaths per year globally. Many chemical pesticides keep it up in the surroundings, leading to pollution of soil and water bodies and contributing to the depletion of the ozone layer (Ngegba *et al.*, 2022).

Before the advent of chemical pesticides, botanical pesticides were extensively used for thousands of years in both subsistence and commercial farming. These botanical pesticides are derived in nature from the chemicals present in plants that function as repellents, attractants, antifeedants and growth inhibitors (Nikkah *et al.* 2017). Once these compounds are correctly mined with the help of solvents and combined with required adjuvants, they get converted into effective botanical pesticides. The rise of synthetic pesticides, due to their effectiveness against severe crop diseases, led to a decline in the use of plant-based products. However, as concerns over the environmental and health risks posed by synthetic pesticides grow, botanical pesticides are experiencing renewed interest, particularly in sustainable farming practices, where their security for crop consumption is valued by consumers, who are ready to pay higher prices for organic synthetic chemical free products (Ngegba *et al.*, 2022).

5. Challenges of Botanical Pesticides

In spite of the struggle between botanicals and chemical pesticides, the latter remains more common in the market (Kekuda *et al.*, 2016). The efficiency of botanical pesticides in the field is greatly reliant on environmental and weather conditions due to their prone to rapid degradation (Sales *et al.*, 2016). Several challenges are associated with botanical pesticides, including pest management timings, extraction methods and storing circumstances in relation to adulteration, preparation effectiveness, decrease of pesticide activity and shelf life. Standardizing pesticides based on plant extracts doses is difficult owing to variations in growing conditions, varietal changes, harvest (Dayan *et al.*, 1992). Formulating these pesticides is also challenging because plant species often contain multiple bioactive constituents with varying chemical properties (Kumar and Singh, 2015).

In the process of commercializing botanical pesticides, there appear some significant obstacles: (a) inadequate availability of botanical raw materials; (b) poor regulation and quality control of active ingredients; and (c) regulatory concerns, including the high costs associated with toxicological evaluations (Fischer *et al.*, 2013). Despite their lower toxicity compared to synthetic pesticides, botanical pesticides must undergo severe registration, environmental and toxicological valuations, similar to synthetic products, especially in low-income countries. Addressing these bottlenecks is crucial for the broader adoption and effectiveness of botanical pesticides (Pavela *et al.*, 2014).

6. Conclusion

Botanical insecticides are becoming increasingly popular in sustainable agriculture and are also finding a role in conventional agriculture. They are often used in pesticide rotations or mixed with conventional products to reduce chemical use without compromising effectiveness or raising costs. Some research suggests that certain plant essential oils can enhance the toxicity of conventional insecticides. Although laboratory studies have shown that botanicals might negatively impact natural enemies or biocontrol agents, field studies indicate they can effectively control pests while preserving beneficial arthropods. In controlled environments like greenhouses or indoor farming, where biological control is a common pest management strategy, botanicals are gaining recognition as important crop protectants, especially for targeted treatments or pest removal just before harvest.

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