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Biopesticides in pest management for sustainable agriculture

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ABSTRACT

Abstract: Biopesticides have emerged as sustainable and eco-friendly alternatives to chemical pesticides, with botanical pesticides playing a significant role in modern pest management. Derived from plant sources, botanical pesticides contain bioactive compounds such as alkaloids, flavonoids, terpenoids, and phenolics that effectively control pests through mechanisms like repellence, feeding deterrence, and growth inhibition. These pesticides are biodegradable, target-specific, and pose minimal risk to humans and the environment, making them highly suitable for integrated pest management (IPM) and organic farming systems. Despite challenges such as variability in efficacy and shorter shelf life, advancements in formulation and increased awareness are enhancing their practical application. Overall, botanical biopesticides offer a promising approach for sustainable agriculture and environmentally safe pest control.

1. Introduction

The excess use of chemical pesticides adversely affects both biotic and abiotic components of environment, leading to pollution of soil, water and air as well as harmful impacts as toxicity, diseases, genetic disorders and bioaccumulation in living organisms. Integrated crop management which emphasizes natural and sustainable approaches has emerged as an effective alternative for controlling pests, weeds and diseases. With increasing concern for environmental safety and the quality of agricultural produce, biopesticides have gained significant importance as eco-friendly tools that support sustainable agriculture and protect ecosystem healthy

Biopesticides are natural, eco-friendly substances derived from plants, animals, or microorganisms, used for pest control with low toxicity, minimal residues, and suitability for organic farming (Sjam et al., 2023; Reddey et al., 2024). Their active ingredients may be single or complex compounds, with botanical insecticides being effective, target-specific, and biodegradable.

Secondary metabolites such as terpenoids, alkaloids, tannins, and flavonoids play a key role in plant defense, making botanical pesticides effective, biodegradable, and non-bioaccumulative alternatives to chemical pesticides (Kulshreshtha and Saxena, 2019; Ushie et al., 2022; Ugwu et al., 2022).

Botanical extracts contain renewable secondary metabolites that enhance phytochemical interactions, reduce metabolism, and help manage pesticide resistance. These plant-derived compounds defend against pests mainly by inhibiting growth and acting as repellents, feeding deterrents, and oviposition deterrents, while remaining largely safe to vertebrates (Taur et al., 2015; Senthil-Nathan, 2013). Plant-derived compounds are highly toxic to many insect species, with over 2000 plant species reported to possess insecticidal properties. Families such as Asteraceae, Lamiaceae, Convolvulaceae, Combretaceae, Thymelaeaceae, Myrtaceae, Apocynaceae, Rutaceae, Lauraceae, and Pedaliaceae are key sources of botanical insecticides (Jeyasankar et al., 2011; Khan et al., 2017; Gorawade et al., 2022; Dash et al., 2022).

2. Review

Many crops are lost each year due to pests, but the introduction of synthetic insecticides has helped to lessen this loss. Nonetheless, the harmful consequences of synthetic pesticides restrict their use and encourage the use of bio-pesticides. Since bio-pesticides have proven to be an effective option to chemical pesticides. Biopesticides can help farmers to reduce their usage of chemical pesticides. Biopesticides are sustainable and environmentally friendly, as well as less dangerous to humans (Singh and Kumar, 2021).

Biopesticides use naturally occurring substances to manage pests in a non-toxic and ecologically friendly. Biopesticides, being living organisms or products, pose less risk to both the environment and human health (Fowsiya et al., 2020). Biopesticides are classified into plant-incorporated protectants (PIPs), semiochemicals, and plant- or microbe-derived substances Bacillus thuringiensis, nuclear polyhedrosis virus, Trichoderma, and neem-based insecticides (Chakraborthy, 2023). They are gaining popularity due to their eco-friendly nature, specificity, efficacy, biodegradability, and compatibility with IPM, though they still form a small share of pest management. Globally, production is increasing (3000 tonnes annually), and in India, their use is regulated under the Insecticides Act of 1968, with several biopesticides being produced and used (Sinha and Ray, 2024).

Biopesticides provide significant benefits for agriculture and public health as they leave no harmful residues, making them safer for consumers, especially in fruits and vegetables. They are effective within IPM systems, offering target-specific action, environmental safety, and biodegradability. Additionally, they require smaller quantities, reduce ecosystem toxicity, and help in resistance management (Mohan et al., 2024).

Products obtained naturally and possessing pesticidal properties is recently attracting the attention of scientists to avoid the effects causing by synthetic compounds. They are strongly interested in their chemical components and biology (Gaaboub et al., 2012). Organic production of perishable products seems to be the best alternative with the least health effects in keeping environment clean. Various plant extracts (phytochemicals) have been tried and suggested for insect-pest control in various field crops (Dhale, 2013) which are safer for the natural enemies, environment, human being and other animals showing low to moderate toxicity to mammals (Singh, 2021).

Plants have an ability to produce a significant range of phytochemicals for self-protection from phytophagous pests, and improve yield without affecting beneficial arthropods. Phytochemicals obtained from plants have been used in control of pests in agriculture, is different in each plant (Tembo et al., 2018).

Researchers have identified thousands of products naturally present in plants and hundreds of thousands are still being screened and isolated for their bioactive properties (Okwute, 2012). A large number of secondary metabolites such as flavonoids, tannins, saponins, terpenoids, phenols, alkaloids, glycosides and steroids have been obtained from medicinal and aromatic plants. These metabolites are known to act insitu roles in avoiding the attacks from pathogenic organisms on plants (Ullah et al., 2018).

Botanical insecticides have an impact on different types of insects by various methods, depending on the type of the plant as well as the physiological characteristics of the insects. The contents of several botanical insecticides can be classified as repellents, attractants, feeding deterrents, chemosterilants and growth retardants (Baidoo et al., 2017). Limonoids, the compound extracted from fruit extract of Melia volkensii, similar to azadiractin has been recorded to be harmful to a broad range of insects such as dipteran, coleopteran and lepidopteran pests (Mwangi, 1987). Leaf extract of Adhatoda vasica was found to posses antifeedant and toxic activity against Spodoptera littoralis (Sedek, 2003).

The phytochemical screening of Citrus aurantium (leaves) showed the presence of volatile oil, terpenoids, saponins, carbohydrates, proteins, phytosterols, tannins and flavonoids but not alkaloids, glycosides or fixed oil. The GC-MS profile of essential oil produced during hydrodistillation from fresh leaves revealed the presence of 35 components (Periyanayagam et al., 2013).

Numbers of phytochemicals are present in different plants at various concentrations which are significant compounds of the human diet. These plants can be used individually or in combination to control any disease or disorder. Bilal et al. (2024) analyzed the phytochemical composition and insecticidal potential of Chrysanthemum cinerariifolium (pyrethrum), reporting varying levels of secondary metabolites in different plant parts. Tannins act as feeding deterrents, flavonoids enhance insecticidal activity, and alkaloids in flowers and roots help control aphids.

According to Kamraj (2008) crude solvent extracts of Ocimum sanctum, Ocimum canum, Rhinacanthus nasutus and Citrus sinensis acts as an efficacious repellent to H. armigera larvae and after the larvae that consumed some amounts of treated leaf showed 100% mortality. Yankanchi and Patil (2009) studied the bioefficacy of plants in which larval density was significantly reduced with 1% treatment of C. inerme and V. negundo extract, and it was proved that infestation percentage is more efficiently reduced than in standard insecticide (10 EC Cypermethrin).

Duraipandiyan et al. (2010) has revealed larvicidal and antifeedant activity of component isolated from Cassia fistula flower ethyle acetate extract i.e. rhein (1,8-dihydroxyanthraquinone-3-carboxylic acid) against S. litura and H. armigera. Effect of crude extracts of Barleria buxifoliain different solvents at four different concentrations was studied by Jeyesankar et al. (2014) for its antifeedant activity in ethyl acetate extract 5 % conc.

Arumugam et al. (2015) proved that, extracts of Rivina humilis in different solvents can be effectively used for antifeedant, ovicidal, larvicidal and oviposition deterrent purpose against Spodoptera litura Significance of Trachyspermum roxburghianum and Terminalia arjuna extract on pest of groundnut H. armigera (Thushimenan et al.,2016). Joes and Sujatha (2017) proved that Methanol extract (1000 ppm) reduced insect larval feeding potential (62.38%), followed by ethyl acetate. Maize grains treated with 2% concentration were observed more toxic.

The feeding deterrence activity of Calotropis gigantea was experimented from its flower, stem, leaf, root and whole plant against H. armigera larvae. The results show less consumption at 10% concentration of all extracts. Root extracts showed highest deterrent activity of 59.00 % and 52.00% against third and fourth instar larvae. Among the different plant parts, leaf extracts showed strong antifeedant effect (Prabhu et al., 2018).

Vetal and Paradeshi (2019) studied larvicidal activity of Argemone mexicana leaf extracts (aqueous and ethanol) on Spodoptera litura at various concentrations. Moringa leaf and seed extract gave larval feeding and antifeedant activity against S. litura (Tridiptasari et al., 2019).

Shiragave (2020) has reported phytochemical profiling and screened Exacum pendunculatum L. extracts of various solvents for insecticidal properties against S. litura. Ali et al. (2021) assessed the effictiveness of various plant extracts (neem seed, marsh pepper, garlic and turmeric) on H. armigera. The methanol extracts of Cromolena odorata and Leonitis nepetifolia evaluated the highest ovicidal activity (Gorawade et al., 2021).

Gorawade et al., (2022) has reported 5 % methanol extract concentration of C. odorata was found effective for larvicidal, ovicidal and antifeedant activities against S. litura. The chloroform and methanol Nerium oleander leaves extract proved to be effective in increased mortality and less rate of adult emergence in H. armigera (Sharma et al., 2023). According to Pavunraj et al. (2024) Cymodocea serrulata extract in ethyl acetate exhibited the significant antifeedant activity against S. litura.

Conclusion

Biopesticides are a sustainable and eco-friendly alternative to chemical pesticides, offering effective pest control with minimal environmental impact and suitability for IPM systems. Although challenges like slower action and limited shelf life exist, recent advancements and growing awareness are improving their adoption. Overall, biopesticides hold strong potential for sustainable agriculture, supported by continued research, policies, and extension efforts.

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