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5. Botanical Insecticides and their Potential to Combat Insect Pest

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Abstract:

The use of agrochemicals has increased recently in order to boost food production for a population that is rapidly expanding on a global scale. However, the careless use of these chemicals, particularly pesticides, has resulted in the build-up of toxic residues in food, soil, air, and water. In turn, this has prompted pests to evolve resistance. The necessity to generate more food sustainably and reliably to fulfill the increasing demand has triggered a quest for natural substitutes to conventional agrochemicals. These alternatives should bolster food security without jeopardizing human health or the environment. Compounds derived from plants possess significant potency, featuring various distinct mechanisms of action, all while maintaining a relatively harmless profile towards unintended organisms. However, challenges like limited stability and technological hurdles hinder the widespread adoption of these plant-based chemicals for pest control. Despite the advantages and disadvantages, the registration and commercialization of botanical insecticides encounter obstacles in India. Issues such as volatile extracts, high costs linked to toxicological assessment, and intricate regulatory approval processes impede their widespread use. While synthetic pesticides are easily accessible in India, it remains imperative to establish regulations for botanical insecticides. This regulatory framework is essential to address the foremost problems associated with their registration and marketing.

Keywords:

Agrochemical, Environment, Residues, Botanicals, Management.

5.1 Introduction:

Insects, diseases, and unwanted plants are responsible for approximately 35% of total agricultural productivity losses on a global scale. In regions with limited resources for pest management, yield reductions can exceed 50%. The combined actions of insects, pests, and pathogens can even lead to complete eradication of crops. Aside from safeguarding crop output and enhancing harvests, ensuring food security hinges on effective crop protection. While Integrated Pest Management (IPM) has gained traction in developed nations, pesticides continue to be commonly employed to control pest populations (Farrar *et al*., 2016). The utilization of synthetic pesticides has risen in both advanced economies and developing countries. Traditional and subsistence farmers still heavily rely on plant-based solutions for pest management. This tradition dates back to ancient times in civilizations such as China, Greece, and India. According to a study conducted in 2018, botanical products are used by as much as one hundred percent of farmers in certain parts of Zimbabwe and Uganda (Dougoud *et al*., 2018).

Across the globe, approximately 2500 plant species from 235 plant families have been documented for their potential in biological pest control (Makaza and Mabhegedhe, 2016; Roy *et al*., 2016). The insecticidal compounds derived from plants are termed botanical insecticides. Plant-based pesticides have received a great deal of attention since the 1980s, making up more than 20 per cent of research articles with an insecticide-specific focus. Common examples of botanical insecticides frequently used include rotenone, sabadilla, nicotine, pyrethrins, ryania, neem, d-limonene, and linalool (Isman, 2020).

5.2 Sources of Botanical Pesticides:

Botanical insecticides can be generated through plant extracts, various essential oils, or a combination of both, sourced from diverse plant categories. These pesticides are derived from a range of plant components, such as roots, seeds, bark, leaves, flowers, fruits, cloves, rhizomes, and stems. Although a substantial number of bioactive compounds are documented, only a limited selection of plant species have undergone comprehensive assessments for their insecticidal properties (Isman, 2006). Among these, only four botanical products – azadirachtin, pyrethrins, rotenones, and essential oils – have successfully made their way into the market. The presence and quantity of the desired bioactive ingredients within the plant part determine the choice of plant part for making botanical pesticides.

Several plant families, including Myrtaceae, Zingiberaceae, Piperaceae, Liliaceae, Sapotaceae, Lauraceae, Lamiaceae, Rutaceae, Asteraceae, Apiaceae, Poaceae, Cupressaceae, Apocynaceae, Solanaceae, Caesalpinaceae have been identified as sources of plants containing varying bioactive compounds with efficacy against significant agricultural insect pests. These plant parts are usually subjected to drying and grinding, creating a finely powdered form for the production of botanical insecticides. The specific molecules of interest are then carefully extracted from these powders using different organic solvents. The resulting extracts are concentrated, prepared, and later tested in labs, under controlled conditions, or in the field for effectiveness.

Plants possess secondary substances that function as feeding deterrents, toxins, and repellents, serving as defenses against insect herbivores. Prior to the 1940s, these natural chemicals were commonly employed to safeguard crops, until the introduction of organochlorines. Among the various classes of commercial botanical insecticides, pyrethrins hold the highest economic significance. These active agents are primarily sourced from *Chrysanthemum cinerariaefolium* flowers and consist of a group of structurally related esters. The most prominent and insecticidal ones fall under the type I pyrethrins category (Schleier and Peterson, 2011). Pyrethrins induce heightened activity and convulsions through their "knock-down" effects. These compounds impact insect neuron membranes, triggering a neurotoxic response that activates sodium (Na^+) channels, resulting in excitation and heightened activity (Davies *et al*., 2007). However, pyrethrins are susceptible to degradation, particularly under UV light. Field studies indicate a half-life of approximately 2 hours, severely limiting their practicality for agricultural pest management (Fantke *et al*., 2014). Despite this vulnerability, pyrethrins remain the most extensively employed botanical insecticides globally and continue to be favored for household insect control purposes.

The roots (rhizomes) of tropical legumes generate a range of isoflavones, among them being rotenones. These highly potent secondary chemicals substantially suppress insect appetite, leading to their demise within a short span of hours or days. Rotenones, which are present in more than 67 species of the Fabaceae family, serve as a non-systemic insecticide with broad-spectrum effectiveness against aphids, thrips, and sap-sucking insects (Xu and Huang, 2001). Unlike pyrethrins, rotenone acts as a mitochondrial toxin, impeding ATP production. Its mode of action involves acting as a stomach poison, necessitating ingestion to take effect. Rotenones exhibit a persistence of 3-4 days upon exposure to air and sunlight, rendering them more enduring compared to pyrethrins (Yang *et al*., 2008). Another noteworthy group of plant-derived secondary compounds is azadirachtin, categorized as a limonoid. As reported by Mondal and Mondal (2012), it boasts a wide-ranging activity spectrum and intricate molecular complexity, effectively targeting around 550 insect species, primarily from orders such as Lepidoptera, Orthoptera, Siphonaptera, Diptera, Dictyoptera, Coleoptera, Thysanoptera, Heteroptera, Homoptera, and Isoptera. Azadirachtin functions as a systemic toxin and a molting inhibitor. Upon exposure, it promptly diminishes hunger and can lead to challenges in egg-laying, infertility, and the suppression of enzyme and chitin synthesis in insects. Furthermore, it can cause delays or disruptions in post-embryonic development (Liu and Liu, 2006).

How botanical pesticides works?

Botanical insecticides are sourced from dried and grounded plant materials, plant extracts, or isolated plant chemicals, and are harnessed for the management of insect pests (Isman, 2008). These insecticides capitalize on plant’s secondary metabolites encompassing non-protein amino acids, glucosinolates, steroids, quinones, phenols, alkaloids, flavonoids, glycosides, terpenoids, and tannins, which confer protective effects against insect pests. The historical use of botanicals traces back to ancient times, with pyrethrum's application as far back as 400 BC. Nicotine, the inaugural botanical insecticide, dates to the 17th century, succeeded by rotenone's introduction in the mid-1800s, and subsequently, sabadilla and other botanical counterparts. Globally, farmers have employed plants or plant extracts containing potent defensive compounds to combat pests in both field and storage godowns.

Botanical insecticides adopt diverse mechanisms, including functioning as deterrents that thwart pests from locating food sources, acting as feeding inhibitors primarily due to terpenes, growth regulators that hinder insect development and disrupt metamorphosis, insecticidal agents leading to death upon contact or ingestion, and repellents generating unpleasant smells or irritations to repel insects (e.g., garlic and hot peppers). The presence of multiple active compounds in plant extracts makes it tougher for insects to develop resistance compared to synthetic insecticides, which often rely on a solitary active compound and mode of action (Hawkins *et al*., 2018). Botanical insecticides, on the other hand, are natural, exhibit swift action, and degrade rapidly, resulting in reduced environmental pollution. They also demonstrate low toxicity and selectivity to livestock and natural predators (with a few exceptions), and minimal risk to mammals. Additionally, botanical insecticides, particularly those sourced from locally cultivated plants, prove to be cost-effective and convenient to apply, offering advantages over their synthetic alternatives (Lengai *et al*., 2020).

5.2.1 Essential oils (EOs) as Botanical Insecticides:

EOs from aromatic plants are being used as insecticides more and more by organic growers and eco-conscious consumers. EOs offers a diverse array of effects on insect such as antifeedent activity, repellency, growth and oviposition inhibitors, ovicidal and growth-limiting effects. In addition to these they have acute contact and fumigant toxicity towards insects (Abdelgaleil *et al*., 2009). EOs lead to insect mortality by impeding acetylcholinesterase (AChE) activity in the nervous system of insects (Houghton *et al*., 2006). Owing to their pronounced volatility and lipophilic characteristics, essential oils exhibit potent toxicity to insects and rapidly permeate their bodies, disrupting physiological functions (Negahban *et al*., 2007).

The notable volatility of EOs also renders them effective when utilized as fumigants and gaseous agents against insects that infest stored products. They showcase intriguing larvicidal impacts on larvae like *Lymantria dispar* (Moretti *et al*., 2000), as well as toxic and repellent properties against ants, cockroaches, bedbugs, flies, head lice, and moths, in addition to being toxic to termites. As an illustration, *Mentha piperita* (peppermint) oil repels ants, moths, flies, and lice, while effectively managing *Tribolium castaneum* and *Callosobruchus maculatus* (Kordali *et al*., 2005). Larvicidal efficacy against *Aedes aegypti* and *Culex quinquefasciatus* mosquito larvae is demonstrated by oil from *Trachyspermum* species (Tripathi *et al*., 2000). The bio-active component, nepetalactone, found in *Nepeta cataria* (Catnip) EO, exhibits remarkable repellent action against bees, mosquitoes, and other flying insects, even surpassing the effectiveness of DEET. EOs originating from rhizomes of *Zingiber officinale* and *Piper cubeba* berries showcase insecticidal and antifeedant properties against *Sitophilus oryzae* and *Tribolium castaneum* (Chaubey, 2012a). *Tagetes* species derived EO exhibits insecticidal properties against *Triatoma infestans* and *Ceratitis capitata*. Moreover, essential oil from *Melaleuca alternifolia* exhibits fumigant action against *Sitophilus zeamais* (Min *et al*., 2016).

Eucalyptus, rosemary, mint, and oregano, mint oil are considered acceptable for treating surfaces or using in fumigation for cockroach control. Adults of *Acanthoscelides obtectus* is killed by the oils of *Eucalyptus globulus*, *Lavandula hybrida*, and *Rosmarinus officinalis* (Papachristos *et al*., 2004). Furthermore, essential oil derived from Tagetes minuta is toxic to Cochliomyia macellaria (Calliphoridae) and has acaricidal and repelling properties. (Chaaban *et al*., 2017). Linalool, another constituent found in basil oil, exerts toxic influence on bruchids and other storage pests, rendering it valuable for combating pests in stored grains or food items. EO of *Juniperus procera* has demonstrated notable repellent properties towards the malarial vector *Anopheles arabiensis*, implying its potential to mitigate mosquito bites and lower the risk of malaria transmission. Eucalyptus species-derived EOs, such as *Eucalyptus cinerea*, *Eucalyptus viminalis*, and *Eucalyptus saligna*, exhibit fumigant and repellent action against permethrin-resistant head lice (Toloza *et al*., 2006). These oils comprise various compounds, including citronellal, citronellol, p-cymene, eucamalol, 1, 8-cineole, citronellyl acetate, α-pinene, limonene, and linalool, contributing to the toxic and anti-feedant effects of eucalyptus oil. Eucalyptus oils enriched with cineole have proven effective against the varroa mite, a significant honey bee parasite, as well as against *Tetranychus urticae* and *Phytoseiulus persimilis*, pests that impact plants (El-Zemity *et al.*, 2006).

5.3 Insecticidal Activities:

Tagetes minuta, *A. indica*, *C. cinerariaefolium*, *A. sativum*, *Mirabilis jalapa*, *Datura metel*, *L. camara*, and *R. speciosa* are a few examples of botanical insecticides that have been successfully used to manage a variety of pests that often attack *Phaseolus vulgaris* L., or common beans. Thrips and aphids, armyworms, grasshoppers, bollworms, cabbage loopers, caterpillars, bruchids, and pink stem borers are some of the pests that infest common bean (Karani *et al*., 2017). Extracts from *Carica papaya* L. and *T. minuta* have demonstrated significant success in reducing aphid populations and curtailing leaf damage. The robust outcomes of these extracts may stem from their diverse array of insecticidal constituents (Murovhi *et al*., 2020). For instance, *C. papaya* leaf extract contains a range of detrimental substances for sucking pests, like spotted bollworms, whiteflies and aphids. These include papain; a group of cysteine protease enzymes, flavonoids, alkaloids, terpenoids, and non-protein amino acids (Zobayer and Hasan, 2013). Phenylpropanoids, carotenoids, flavonoids, the phototoxin alphaterthieenyl, and thiophenes are all present in *T. minuta* leaf extracts and have all been shown to be successful in reducing insect infestations (Dunkel *et al*., 2010).

Azadirachtin, another botanical pesticide, operates through various mechanisms, including deterring feeding, influencing morphology, reducing fitness, suppressing reproduction, inhibiting growth, and even sterilizing pests (Zhang *et al*., 2018). In species like *D. melanogaster*, *S. frugiperda*, and *Callosobruchus maculatus*, azadirachtin has been observed to disrupt metamorphosis, leading to delayed pupation and diminished growth from larvae to pupae (Asaduzzaman *et al*., 2016). The higher amounts of azadirachtin and nimbin in neem bark extract make it more effective against lepidopteran pests than neem leaf extracts (Ahmad *et al*., 2018). Increased concentrations of neem oil have been linked to heightened mortality rates and physical impairments in pests' wings, legs, and scutellum (Zanuncio *et al*., 2016).

Against *Phenacoccus solenopsis* and *Aphis gossypi*, extracts of the leaves of *A. indica*, *Eucalyptus globulus* and *O. sanctum* and showed significant insecticidal potential in laboratory experiments (Singh *et al*., 2012). Furthermore, neem leaf extract has proven effective in reducing egg laying and adult survival rates of pests infesting stored grains and seeds (Ahmad *et al*., 2015). Plants are better able to fend off aphids when organic fertilisers are used in conjunction with neem leaf powder and boiler ash. Significant morphological abnormalities and delayed adult development in *D. melanogaster* have been linked to azadirachtin exposure during the pupal stage. In addition, azadirachtin exhibits potent antifeedant effects on *Galleria mellonella*, *Drosophila melanogaster* and *Plutella xylostella*. (Kilani-Morakchi *et al*., 2017) and also been reported to have sublethal effects on mating and post-mating behavior of *D. melanogaster* (Aribi *et al*., 2017) and reduces fecundity in this species (Abedi *et al*., 2013). These effects are attributed to the disruption of pathways leading to synthesis of 20-hydroxyecdysone and juvenile hormone, causing incomplete development of larvae, sterile eggs, and decreased reproductive capacity. Azadirachtin has been shown to cause 100% mortality in tobacco whitefly, *B. tabaci* after 72 hours of oral ingestion. In laboratory trials, 10% turmeric dust caused 80% mortality in pests such as *Amrasca devastans*, *Dysdercus cingulatus*, *Urentius hystricellus*, *Aphis gossypii*, *Earias vittella*, *Cnaphalocrosis medinalis*, *Oxya nitidula*, *Oxycarenus hyalinipennis*, *Epilachna vigintioctopunctata*, *Coccidohystrix insolitus*, *Anomis flava*, *S. litura*, and *Tetranychus neocaledonicus* (Sankari and Narayanasamy, 2007).

Furthermore, palmarosa, turmeric, and clove plant oils have been reported to suppress feeding activity in *S. frugiperda* caterpillars in the early instar stages (Sousa *et al.*, 2018). EOs have been shown to serve as anti-feedants, repellents, and oviposition deterrents, as well as larvicides, ovicides, and insecticides, interfering with different metamorphological stages of insects (Sarma *et al.*, 2019). Turmeric leaf EO has been demonstrated to be effective against three important stored product beetles, *R. dominica*, *S. oryzae*, and *T. castaneum*, when used as a contact or fumigant (Tripathi *et al*., 2001). EOs like eucalyptus and rosemary have repellent effects on various insect species, including vectors (Pavela *et al*., 2011) by acting as a neurotoxin, leading to hyperactivity, followed by rapid knockdown and immobilization (Enan, 2001).

The insect pests suffocate due to allicin, derived from garlic bulbs (*A. sativum*), causing toxic effects on their neurotransmitter receptors (Baidoo and Mochiah, 2016). *Tagetes* spp. ethanolic extracts within the range of 2.8-5.8 percent (w/w) were effective in preventing the development and expansion of *S. frugiperda* (Tavares *et al.*, 2009). *E. globulus* leaf powder showed insecticidal activity against *Prostephanus trunatus*, as reported by Mukangas *et al*. (2010). Acting as a respiratory toxin, *Dalbergia saxatilis* leaf powder provided protection against the cowpea bruchid, *C. maculatus* (Okwute *et al*., 2009). *Piper guineense*, *Piper longum*, and *Piper retrofractum* extracts displayed a success rate of 96-100% in killing *Culex maculatus*, *Zonocerus variegatus*, and mosquito larvae within 48 hours (Dyer and Richard Dodson, 2004). *S. litura* fourth instar larvae exposed to *O. sanctum* oil (1000 ppm) exhibited a mortality rate of 13.33% (Baskaran *et al*., 2012). Additionally, clove oil resulted in the second-highest mortality rate (93.33%), following saunf and khas oil (100%). Both the rhizome and aerial components of the plant yielded extracts that demonstrated dosage mortality activity towards adult of *T. castaneum* (Abida *et al*., 2010). Treatments with onion (*Allium cepa*) or ginger (*Zingiber officinale*) significantly reduced populations of the tomato fruit worm (*Helicoverpa zea*) by 70-80%. Shah *et al*. (2013) found that extracts from *Curcuma longa*, *Ferula asafoetida* and *A. sativum* resulted in a substantial reduction in larval and pupal population of *H. armigera*.

5.4 Botanicals in India:

With India's extensive historical use of neem for various medicinal uses and safeguarding stored products, it's reasonable to infer that botanical pesticides are a standard component for Indian farmers. The country also boasts the highest count of organic producers (approximately 650,000) (Willer and Lernoud, 2015) and a significant volume of research on plant-based insecticides. As of 2012, the Ministry of Agriculture has granted licenses for nine botanical insecticides (Bambawale and Bhagat, 2012). The following plant extracts (together with the relevant active components) have also been authorised and are marketed, in addition to garlic and neem: *Milletia pinnata*, *Pongamia glabra* (karanjin, a furanoflavonol); *Annona squamosa* (squamocin and related acetogenins); *Apocynum venetum* (cymarin and/or related cardenolides); *Tripterygium wilfordii* (wilfordine and related diterpenoid epoxides); *Cymbopogon* spp. (monoterpenes, particularly citronellal and citral); *Eucalyptus globulus* (1, 8-cineole and other monoterpenes).

5.5 New Generation of Botanical Insecticides: Issues and Perspectives:

Plant-based and synthetic pesticides compete fiercely for market domination, with the former being less prevalent. Moreover, the field performance of plant-based pesticides relies significantly on current environmental and climatic conditions due to their rapid degradation. It is clear that there are issues with contamination and preparation potency, loss of pesticide effectiveness, and shelf life. Standardizing dosages for botanical pesticides might be challenging due to factors such as varying growth habitats, varietal variation, harvesting time, extraction method, and storage conditions. The intricate task of formulating botanical pesticides arises from the presence of multiple bioactive components in a single plant species, each possessing distinct chemical attributes.

The industrialization of plant-based pesticides encounters notable hurdles, encompassing: (1) the scarcity of botanical raw materials; (2) insufficient standardization and quality control of essential active ingredients; and (3) regulatory approval difficulties, involving costly toxicological assessments of botanical pesticides (Isman and Paluch, 2011). Botanical pesticides are safer than synthetic ones, but their uses in agriculture are regulated in much the same way. This is especially true in developing nations. Stringent environmental, toxicological, and registration evaluations are mandatory due to regulatory constraints, creating bottlenecks for these products.

5.6 Conclusion:

In economically disadvantaged nations, the utilization of botanical pesticides holds significant importance. While botanical insecticides might display reduced efficacy compared to synthetic counterparts, they remain a practical option, especially when integrated with Integrated Pest Management (IPM). This is particularly pertinent in regions where farmers lack access to commercial pesticides or can only afford a limited range of synthetic options. It is important to recognise and share information about the risks associated with using natural pesticides, such as their questionable efficacy and possible negative effects on human health and the environment. To strike a balance between safeguarding crops and mitigating the drawbacks of synthetic insecticides, plant-derived natural insecticides are embraced as a prime alternative to traditional pesticides. The realm of botanical insecticides encompasses diverse compounds and modes of action, influencing insects in various ways. Consequently, in more affluent nations, organic crop cultivators opt for these botanical insecticides over their synthetic counterparts.

Efforts are being directed towards promoting the adoption of botanical pesticides, along with ongoing research to discover new sources of botanical insecticides. Due to the large volume necessary for plant-based pesticide manufacture, active cultivation of plant sources should be performed to ensure a consistent supply of raw materials for industrial usage.

Overcoming formulation challenges, refining active ingredients, determining optimal application rates, enhancing storage stability, and addressing susceptibility to UV light can potentially aid the commercialization of botanical pesticides. For the successful entry of botanical pesticides into the market, collaboration among researchers, investors, manufacturers, marketers, and farmers is imperative. To substantiate the sustained benefits that warrant the integration of botanical pesticides, concerted efforts are essential. Given global concerns about environmental safety, government agencies must intensify their initiatives to educate farmers and manufacturers about the merits of transitioning to botanical pesticides as part of a sustainable pest management strategy.

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