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Unveiling the Future of Agriculture with Green Pesticides

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ABSTRACT

Synthetic insecticides have been a common practice in pest control for many years. Tons and tons of pesticides have been consumed by the filed for producing the food consumed by the human race. Although, we know that the chemical pesticides are not only harmful to us, rather they are also harmful to flora and fauna. However, concerns about their negative environmental and human health impact have prompted a search for alternative methods. Natural insecticides, derived from plants or other natural sources, have gained attention as a potential alternative. This current review provides an overview of the advantages of natural insecticides over synthetic ones, including their low toxicity to humans and other non-target organisms, biodegradability, and sustainability. Additionally, it highlights the effectiveness of certain natural insecticides, such as henna, neem oil, and ginger, in controlling pests. While there are some limitations to the use of natural insecticides, including their sometimes-lower efficacy and shorter shelf life, they offer a promising solution to the problems associated with synthetic insecticides. Moreover, the use of green pesticides may also increase the economic status of the farmers and open up new route for discovery. Finally, this paper argues that a shift towards the use of natural insecticides is necessary to promote a safer and more sustainable approach to pest control.

Keywords:*Natural insecticide, Synthetic insecticide, Non-target organism, Human health, Resistance, Pest control.*

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INTRODUCTION

In the intricate tapestry of our natural world, insects play an essential role, from pollinating plants to decomposing organic matter. However, there exists a delicate balance between the benefits these creatures bestow upon ecosystems and the challenges they pose to human endeavours, particularly in agriculture. Insecticides can be defined as a group of chemical warriors designed to combat the relentless onslaught of insect pests that threaten our crops and food security. Insecticides have become both a shield and a double-edged sword, wielding the power to bolster agricultural productivity while raising concerns about their ecological impact and potential human health risks. Insecticides have played an indispensable role in modern agriculture, safeguarding crops against a plethora of destructive pests that threaten global food security. These chemical formulations have significantly boosted crop yields and protected valuable plants from relentless insect attacks. However, the extensive use of insecticides has also raised concerns about their impact on the environment, non-target species, and human health. Insecticides are chemical or biological substances utilized to manage insects by eliminating them or obstructing their harmful activities. Incorrect handling or application of pesticides can lead to immediate health effects, including skin and eye irritation, nausea, vomiting, dizziness, headaches, and even more severe symptoms in cases of acute poisoning. Prolonged exposure to low levels of pesticides, especially for agricultural workers and communities near treated areas, has been associated with an increased risk of chronic health issues such as cancer, neurological disorders, respiratory problems, and reproductive issues. Chemical pesticides can harm unintended organisms, including beneficial insects, birds, fish, and amphibians. This can disrupt ecosystems and lead to a decrease in biodiversity. Pesticides can leach into groundwater or run off into nearby water bodies, leading to contamination of drinking water sources and aquatic ecosystems. Pesticides can negatively affect soil quality, reducing microbial diversity and nutrient availability, which can ultimately impact the health of plants and the sustainability of agricultural systems. Repeated use of the same chemical pesticides can lead to the development of resistance in target pests, rendering the pesticides less effective over time. This can necessitate the use of higher doses or more toxic chemicals, exacerbating the problem. When pesticides kill off natural predators and competitors of pests, it can lead to an increase in the population of secondary pests, which were previously kept in check by the ecosystem. Pesticide residues can remain on crops even after harvest, potentially leading to ingestion by consumers. While regulatory agencies set limits on allowable residue levels, concerns about chronic exposure persist. Long-term consumption of pesticide residues in food has been associated with potential health risks, including cancer, developmental issues, and hormonal disruption. These substances can either occur naturally or be human-made and are available in various forms and delivery methods, such as sprays, baits, and slow-release diffusion, to target specific pests. There are many different classes of insecticide present which include-

Organochlorines

Organochlorines are a type of insecticide composed of carbon, hydrogen, and chlorine, and are alternatively referred to as chlorinated hydrocarbons, chlorinated organics, chlorinated insecticides, or chlorinated synthetics [1].

Diphenyl aliphatics, a group of organochlorine insecticides including DDT, DDD, dicofol, ethylene, chlorobenzilate, and methoxychlor, are the oldest of their kind. DDT, in particular, is widely recognized as the most infamous chemical of the 20th century, yet it remains a fascinating compound and is still considered one of the most effective insecticides. In 1939, Dr. Paul Muller, a Swiss entomologist, was awarded the Nobel Prize in Medicine for his discovery of DDT as an insecticide that could effectively control the spread of malaria, yellow fever, and various other insect-borne diseases, ultimately saving countless lives [1].

Hexachlorocyclohexane (HCH), also known as benzene-hexachloride (BHC), contains five isomers - alpha, beta, gamma, delta, and epsilon - in its technical grade. Interestingly, only the gamma isomer exhibits insecticidal properties, leading to its isolation during manufacturing and commercialization as the odorless insecticide lindane [1].

Polychloroterpenes, yielded only two insecticides, toxaphene in 1947 and strobane, both of which were limited in availability. When used alone, toxaphene demonstrated weak insecticidal properties and was therefore initially combined with DDT for use on cotton crops [1].

Organophosphates:

Insecticides “Organophosphates" or OPs. Other obsolete names for these chemicals include organic phosphates, phosphorus insecticides, nerve gas relatives, and phosphoric acid esters. OPs possess two notable characteristics: they are typically more harmful to vertebrates than other types of insecticides and chemically unstable or non-persistent. OPs are categorized into three groups based on their chemical structure: aliphatic, phenyl, and heterocyclic derivatives [1].

Organosulfurs

Organosulfurs, a small group of compounds, have minimal insecticidal properties and are exclusively used as acaricides (miticides). These substances consist of two phenyl rings that resemble DDT but with sulfur occupying the central position instead of carbon. Examples of such compounds include tetradifon (Tedion®), and propargite (O) [1].

Carbamates

Formamidines, a small group of insecticides, includes compounds such as chlordimeform (Galecron®, Fundal®), which is no longer authorized for use in the U.S., formetanate (Carzol®), and amitraz (Mitac®, Ovasyn®). These insecticides are particularly useful in controlling pests that have developed resistance to OPs and carbamates [1].

Dinitrophenols

The dinitrophenol compound has multiple toxic properties, including herbicidal, insecticidal, ovicidal, and fungicidal. Two examples of insecticides within this group are binapacryl (Morocide®) and dinocap (Karathane®), with dinocap also being a potent miticide and fungicide against powdery mildew fungi. However, all dinitrophenols have been removed from use due to their high inherent toxicity [1].

Organotins

The group of organotins acts as both acaricides and fungicides.Fenbutatin-oxide (Vendex®) is a type of organotin acaricide that also functions as a fungicide and has been widely utilized to control mites on deciduous fruits, citrus, greenhouse crops, and ornamental plants [1].

Nicotinoids

Neonicotinoid pesticides, while posing less harm to humans compared to nicotine, exhibit similar properties to the latter. These compounds are toxic to insects and some invertebrates, disrupting their central nervous systems and resulting in mortality. Additionally, neonicotinoids have been found to impact the reproduction, foraging, and flying capabilities of honeybees and other pollinators [2].

Fiproles (or phenylpyrazoles)
Fiprole insecticides, which belong to the phenylpyrazole class and include ethiprole, fipronil, and flufiprole, play a significant role in controlling rice planthoppers in Asia. However, the emergence of resistance to fiprole insecticides, particularly in L. striatellus, has become a growing concern. The development of cross-resistance among fiprole insecticides highlights the need for effective management strategies to mitigate resistance and maintain their efficacy [3].

Pyrroles
Chlorfenapyr, a pyrrole insecticide, stands out for its lack of cross-resistance to commonly used insecticide classes in vector control. It has demonstrated effectiveness on mosquito nets in experimental hut conditions. Unlike neurotoxic insecticides, the mode of action of Chlorfenapyr involves disrupting metabolic pathways within mitochondria, which are essential for cellular respiration, and contributes to its toxicity [4].

Pyrazoles
Synthetic pyrazole compounds have demonstrated significant pre-emergent herbicidal activity against a wide range of weed species. Additionally, pyrazoline-type insecticides derived from synthesis have been observed to target neuronal sites, effectively impacting insect pests [5].
Pyridazinones
The compound oxadiazolyl 3(2H)-pyridazinone exhibited notable inhibitory effects on the growth of P. separata, leading to delayed development and an extended larval period. Additionally, it caused reduced body size, sluggish behavior, delayed pupation, and decreased eclosion rate of both pupae and adults. Furthermore, the compound strongly suppressed the activities of the weak alkaline trypsin-like enzyme, chymotrypsin-like enzyme, and alpha-amylase in the midguts of fifth instar P. separata larvae [6].

Benzoylureas
Benzoylurea chitin synthesis inhibitors have gained significant popularity in integrated pest management (IPM) and insecticide resistance management (IRM) programs. This is attributed to their advantageous feature of low toxicity towards mammals and predatory insects [7].

Impact of synthetic insecticide on the Environment:
The Synthetic chemical which is meant for killing insects is causing ecosystem imbalance. The toxicity of those chemicals affects the environment globally [8]. Due to their high biological activity and toxicity, synthetic insecticide causes environmental contamination. The improper, inadequate use of these synthetic insecticides in crop insect management throughout causes tremendous damage to the environment, development of resistance in target insects, and deleterious effects on non-target organisms [9]. The most acutely toxic class of pesticide is an insecticide which can affect the non-target organism also [10].
Synthetic insecticide affects water, soil, and air. The direct application of insecticide for aquatic weeds causes effects both on ground and surface water. The residue of insecticide affects the soil after being left there for many years. The insecticide affects the air by its volatilization and mixes with the air [11]. Extreme uses of synthetic insecticides lead to the destruction of biodiversity. Use of this causes global instability and effecting the sustainability of the environment, also due to the illiteracy of the farmers they apply insecticide without proper information which causes a hazardous effect on the environment [12].

Impact of synthetic insecticide on Human Health:
Even though there are many strict rules and regulations on the registration and use of insecticides, it is a matter of concern because of their direct impact on human health. Environmental contamination and occupational use automatically expose people to a cocktail of insecticides. Every group of persons is either directly or indirectly exposed to insecticides and has considerable complexity in human health due to most of the diseases [13].
There is a variety of insecticide that exists. At low concentrations, they may not show acute detectable effects but long-term use of this may cause genetic disorders or physiological disorders[14]. DDT is an organochlorine pesticide which had caused much-uncontrolled damage to human-like, endocrine disorders, and hepatic and hematological alteration. Organophosphorus shows a negative effect on the

male reproductive system and nervous system. Carbamate shows cytotoxic and genotoxic effects in hamster ovarian cells and also shows necrosis and apoptosis in the human body [15].
Synthetic insecticides show an extremely toxic effect on pregnant women, they increased the risk of many birth-related defects such as preterm birth or low birth weight, and abnormality in the fetus. Newborns and young children are facing the neurotoxic effect of insecticides higher than adults. It is also impacting the mental development of babies [16].

Mechanism of action of pesticides:
Plants synthesize a range of bioactive compounds to defend themselves against predators and diseases, which can be extracted and utilized as natural insecticides. These bioactive compounds comprise fatty acids, alkaloids, terpenoids, limonene, thymol, phenols, and quercetin, among others. Insects and mites of small size are effectively killed by an insecticide that contains fatty acid salts, which function by suffocating them. This is accomplished through the obstruction of spiracles, as well as the disruption of waxes present in the cuticles and membranes of the integument, ultimately resulting in desiccation [17].
Alkaloids, which are compounds containing nitrogen and possess diverse biological activities, are frequently utilized as a source of insecticides. Nicotine, a prominent alkaloid, is toxic to insects because it interferes with their nervous system. This attribute has been utilized in agriculture, where nicotine sulfate is utilized as an insecticide to manage pests such as aphids in crops [18].
Terpenoids, a large class of compounds produced by plants, are also commonly used as insecticides.Azadirachtin, a terpenoid found in neem oil, is an effective insecticide that disrupts insect growth and development [19].
Phenols, which are present in several plant species, have insecticidal and antimicrobial properties that make them useful for various applications. Eucalyptol, a phenol present in eucalyptus oil, is a toxic compound that targets several insect pests and is widely used as an insecticide to manage mites and other pests in crop production [20].
Limonene, is a powerful insecticide belonging to the monoterpene class, which is extracted from citrus fruits. It targets the nervous system of insects, leading to its insecticidal effects [21].
Thymol, a phenolic compound found in thyme, possesses insecticidal activity against various insect pests like beetles and mites. Its mode of action involves the disruption of the cell membrane of insects [22].
Quercetin, a flavonoid, is a promising compound for the development of bio-insecticides due to its association with the defence mechanism of plants. It plays a role in altering the palatability and nutritional value of the plant, decreasing its digestibility, and even acting as a toxin to protect the plant against pests [23].
Bacillus thuringiensis is a type of Gram-positive bacteria that produces Bt toxins, which are insecticidal proteins. These toxins have demonstrated targeted toxicity towards certain types of insects such as caterpillars, beetles, and mosquitoes by attaching to particular receptors found on the insects' midgut cells, thereby resulting in cellular damage and breakdown.[24]

Advantages of natural insecticides:

1. Natural insecticides barely harm humans and animals, also they leave very less residue in the soil. Natural insecticides offer a diverse range of active compounds and complex modes of action, making it harder for pests to develop resistance and prolong their effectiveness [25].
2. Bt has proven to be extremely effective in controlling pests in corn and cotton crops, leading to a significant reduction in the use of broad-spectrum chemical insecticides. Moreover, its usage ensures the safety of consumers and non-target organisms [26].
3. They are less persistent than some synthetic insecticides and they have a tendency to degrade in the environment, resulting in the absence of any lingering activity after a relatively brief period [27].
4. Many natural insecticides exhibit selective toxicity, meaning they specifically target and affect certain pests while having minimal impact on beneficial insects, such as pollinators and natural predators. This targeted approach helps maintain a more balanced and sustainable ecosystem [28].
5. Natural insecticides are an important component of organic farming practices. They are permitted for use in organic agriculture, as they align with the principles of sustainability, ecological balance, and reduced chemical inputs. This makes them an essential tool for farmers seeking organic certification or aiming to adopt more sustainable farming methods [29].

Efficacy and Stability of natural insecticide:
The efficacy and stability of natural insecticides can vary depending on the specific product and application. While natural insecticides are generally considered safer and more environmentally friendly

than synthetic chemical insecticides, their effectiveness and persistence can be influenced by several factors.
One commonly used natural insecticideis neem oil, derived from the seeds of the neem tree (Azadirachta indica). Neem oil contains several compounds, such as azadirachtin, which have insecticidal properties.
A study published in the Journal of Economic Entomology in 2013 examined the efficacy of neem oil against the brown marmorated stink bug, an invasive pest that causes significant damage to various crops. It was found that neem oil effectively suppressed the stink bug population and reduced feeding damage on treated plants. The study concluded that neem oil can be a valuable tool for managing this pest [30].
Another commonly used natural insecticide is pyrethrum, which is derived from the flowers of certain chrysanthemum species. Pyrethrum contains natural insecticidal compounds called pyrethrins, which are effective against a wide range of insect pests.
A study published in the Journal of Economic Entomology in 2012 evaluated the efficacy of pyrethrum-based insecticides against different insect pests. It was found that pyrethrum-based products provided effective control of various pests, including mosquitoes, flies, beetles, and aphids. The study concluded that pyrethrum-based insecticides can be a valuable tool in integrated pest management programs [31].

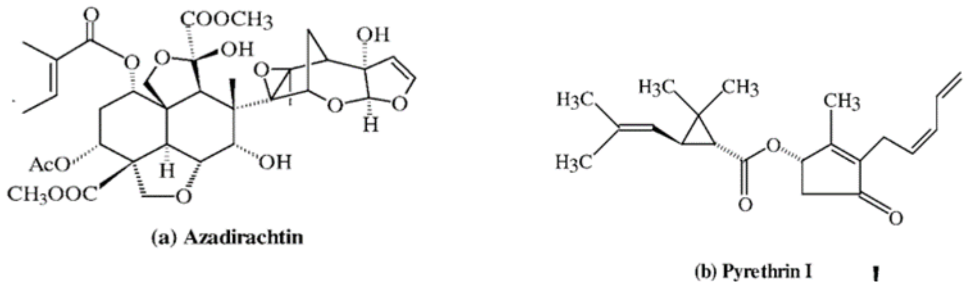

Figure 1: Active constituents of some botanical insecticides from a. neem (Azadirachtin) and b. Pyrethrum (Pyrethrin I)
Regarding stability, the persistence of natural insecticides can vary depending on factors such as environmental conditions, application method, and formulation. Many natural insecticides degrade more rapidly compared to synthetic chemical insecticides, which can be an advantage in terms of minimizing environmental impact. However, this also means that they may require more frequent applications. However, their stability may be influenced by factors such as exposure to sunlight, moisture, temperature, and microbial activity [32].

Currently available insecticides in the market and their drawbacks related to their uses on human health:
Organochlorine, organophosphorus, carbamate, Triazines, and neonicotinoids are some types of insecticides that are currently available. There are many health effects related to those insecticides.
Organochlorines that are used as insecticides are DDT, Dieldrin, Endosulfan, Heptachlor, Dicofol, and methoxychlor. Among those DDT is the most widely used organochlorine. As per the global report, DDThas major health impacts, so it has been banned in many countries. But some countries are still using this insecticide to control insect-born malarial disease and leishmaniasis. Major health problems associated with DDT are endocrine disorders, effects on embryonic development, lipid metabolism, hepatic alteration, and hematological problem [33].
The most commonly used organophosphate insecticides are Parathion, Chlorpyrifos,Diazinon, Dichlorvos, Phosmet, Fenitrothion, Tetrachlorvinphos, Azamethiphos, Azinphos-methyl, Malathion, Methyl Parathion. Organophosphate exposure can occur by inhalation, direct insecticide contact, or food ingestion. Around 33 million people are affected by organophosphate worldwide, with 3lakh mortality cases. There are many health problems associated with organophosphate toxicity which are like -

- Respiratory System associated problems are respiratory failure, aspiration pneumonia, non-cardiogenic pulmonary edema
- Cardiovascularsystem-associated problems are hypertension, hypotension, and Bradycardia. Arrhythmias.
- Central nervoussystem-associated problems are Seizures, Hallucinations, mental health problem
- Renal system-associated problems are acute kidney problems [34].

Carbamate insecticides are like aldicarb, carbaryl, propoxur, oxalyl, and terbucarb. Carbamate shows major toxicological problems in developing countries. Serious issues related to these insecticides are myocarditis, cognitive, regressive psychosis seizures, anxiety, muscular damage, and ventricular arrhythmias [35].
Neonicotinoids are broad-class insecticides that are dominating the global market. The health effect of NEOs is neurological toxicity and diabetic problem in non-targeted organisms. They are exposed to blood urine, saliva, breast milk, and hair [36].
Agriculture's most commonly used triazine insecticides are atrazine, cyanazine, propazine, simazine, and terbuthylazine. Triazines show many health problems like skin irritation and eye irritation. Atrazine shows a carcinogenic effect on humans, defects innewborns, and neck and head cancer [37].

Plants with potential insecticidal effects:
Many plants showthe potential insecticidal effect which includes-

1. Annona muricata & Annona squamosa: The oil and aqueous extract of seeds of plants *A. muricata* and A. squamosa shows insecticidal properties against mosquitoes Aedes albopictus and Culex quinquefasciatus [38].
2. Allium sativum L: The ethanolic extract of the leaf and bulb of *Allium sativum* L shows insecticidal properties against the pest Pseudomonas syringae [39].
3. Azadirachta indica: Aqueous, Ethanolic and Methanolic extraction of plant *Azadirachta indica* shows insecticidal properties against *Fusarium oxysporum*, *Sitophilus zeamais* [40, 41].
4. Brassica campestris: The methanolic plant extracts of Brassica cempestris show insecticidal and repellent activity against the red flour beetle Tribolium castaneum [42].
5. Citrullus colocynthis: Citrullus colocynthis shows natural insecticidal properties to some extent, which can be used against cabbage aphids, and B. brassicae [43].
6. Capsicum frutescens: The crude and ethanolic extracts of Capsicum frutescens fruit show antibacterial activity against some bacterial pathogens *Escherichia coli, Staphylococcus aureus, Bacillus subtilis*, and *Pseudomonas aerugionsa*) [44].
7. Citrus hystrix DC: The insecticidal effects of essential oil derived from Citrus hystrix leaves were studied against Spodoptera litura, using a laboratory-based topical application bioassay on second instar larvae.The research found that the essential oil demonstrated significant efficacy in killing the larvae, with an LD50 value of 26.748 μL/g [45].
8. *Coriandrum sativum* L.:The essential oil extracted from Coriandrum sativum demonstrated toxicity against Aedes albopictus larvae, with an LC (50) of 421 ppm and an LC (90) of 531.7 ppm. Additionally, repellence trials revealed that the C. sativum EO was an effective repellent for Aedes albopictus, even at lower doses, with an RD (50) of 0.0001565 μL/cm (2) of skin and an RD (90) of 0.002004 μL/cm (2). When applied at the highest dosage of 0.2 μL/cm (2) of skin, the protection time provided by the Coriandrum sativum essential oil was over 60 minutes [46].
9. *Curcuma longa* L: A study provides evidence that curcumin can induce autophagic cell death in the Sf9 insect cell line, and it represents the first reported instance of curcumin's cytotoxic effects on insect cells [47].
10. *Datura stramonium* L:The Soxhlet's extracted extracts of *Datura stramonium* seed in ethanol, chloroform, and acetone were very effective to control the pest. The findings indicate that both the concentration and duration of exposure were positively correlated with mortality, meaning that higher concentrations and longer exposure times resulted in increased rates of death [48].
11. *Lawsonia inermis*:The toxicity of the ethanolic leaves extract of Lawsonia inermis was tested on 4th instar larvae of Culex quinquefasciatus using three different concentrations (25000, 5000, and 75000 ppm). The findings indicated that as the concentration levels and duration of exposure increased, there was a corresponding increase in mortality rates of the larvae, suggesting that the plant extract could be an effective natural insecticide against Culex quinquefasciatus [49].
12. Lantana camara:The study examined the insecticidal properties of methanol, ethanol, and ethyl acetate extracts of Lantana camara leaf oil and powder for managing Sitophilus zeamais, commonly known as maize weevils. Results revealed that the methanol extract had the highest percentage mortality rate (74%) among all treatments applied, while the ethyl acetate extract had the lowest (26%) at a concentration of 2% (w/w). The mortality rate increased as the exposure time was extended. The presence of bioactive and phytochemical molecules like Phytol, Pyrroline, Paromomycin, Pyrrolizin, and 1-Eicosano in the leaf powder and extracted oil contributed to their effect on repellency and mortality in insects [50].
13. Mentha piperita L.: The essential oil derived from Mentha piperita exhibited remarkable efficacy in killing dengue vector larvae. Results of the bioassays revealed that after 24 hours of exposure, the oil

had an LC50 value of 111.9 ppm and an LC90 value of 295.18 ppm, indicating its potent larvicidal properties [51].

14. Nicotiana tabacum: The ethanolic heat reflux extract of *Nicotiana tabacum* shows insecticidal activity against Galleria mellonella and Gryllus bimaculatus. According to a study the LC_{50} value for *Galleria mellonella* and Gryllus bimaculatus was found to be 36.6 mg/ml and 38.5 mg/ml, respectively [52].

15. *Zingiber officinale* Roscoe: In this study, four unrefined extracts derived from the rhizomes of Zingiber officinale were examined for their ability to cause contact toxicity in second instar larvae of *Spodoptera litura*, *Spodoptera exigua*, and *Spodoptera frugiperda* through topical application. Results demonstrated that the hexane extract displayed the highest level of toxicity against S. exigua, exhibiting LD50 values of 9.92 and 8.40 µg/larva after 24 and 48 hours of treatment, respectively. The toxicity of the hexane extract was found to be less effective against S. frugiperda in comparison to S. exigua [53].

Bioactive components having a potential insecticidal effect:

Bio means life and active means dynamic. Bioactive means biologically active.A substance is considered to have biological activity when it produces a direct impact on a living organism. The effects can vary widely, with some being beneficial for maintaining health or even promoting healing, while others can be harmful and even fatal. The impact of bioactive compounds depends on factors such as the substance itself, the dosage, and its bioavailability. Thus, the positive or negative effects of these compounds are often determined by the amount ingested[54]. Numerous bioactive compounds found in plants, including polyphenols, phytosterols, biogenic amines, carotenoids, and biologically active proteins, have been linked to various health benefits in humans, including protection against cancer, cardiovascular diseases, diabetes, as well as improvements in gut health, immune function, and neurodegenerative disorders. Scientific studies have shown that these compounds possess a range of beneficial properties, including antioxidant, anti-inflammatory, and immunomodulatory effects [55].

Many bioactive compounds found in various plant which works as insecticide are discussed below: The insecticidal properties of beauvericin were initially discovered by Hamill et al., who confirmed its efficacy as the active compound from B. bassiana against Artemia salina, a model organism for studying insecticidal activity. Beauvericin's effectiveness was subsequently evaluated on Calliphora erythrocephala, Aedes aegypti, Lygus spp., Spodoptera frugiperda, and Schizaphis graminum at a microgram level [56].

The trans-anethole, a major insecticidal agent in anise oil derived from anise tops, had an LD50 of 75µg/fly when applied topically to houseflies, having an insecticidal effect. The toxicity of nine other anise compounds, namely anisaldehyde, estragole, anisyl alcohol, anisic acid, p-cresol, p-creosol, eugenol, hydroquinone, and acetaldehyde, was also evaluated on houseflies. When applied together with parathion, both anethole and anisaldehyde were found to increase toxicity to houseflies [57].

Limonoid from Melia azedarach was found to have insecticidal activity [58].

The traditional herbal remedy Podophyllum sinense, which has a high concentration of lignans, flavonoids, anthraquinones, and volatile oils, has insecticidal properties [59].

The medical plant Terminalia arjuna has insecticidal qualities because it contains phytochemicals such as triterpenoids, glycosides, flavonoids, and tannins [60].

A component of Artemisia lavandulaefolia essential oil known as (-)-4-terpineol has insecticidal effects on the common pest Plutella xylostella [61].

The essential oil of Mentha pulegium L. contains pulegone and piperitenone, which possess fumigant properties against Sitophilus oryzae [62].

Isoflavones found in chickpeas (Cicer arietinum), such as biochanin A and biochanin B, have insecticidal effects [63, 64].

The essential oil made from Dyssodia tagetiflora, which is made up of six monoterpenes, has insecticidal action against Drosophila melanogaster larvae [65].

CONCLUSION

In conclusion, it has been seen that plant extracts have the potential to control the pests/insects in crops without majorly harming the environment, and humans, whereas synthetic pesticides/insecticides show a massive impact on the environment and humans. The stability or efficacy of natural insecticides may be limited. Additionally, the potential environmental impact of biopesticide must also be considered. For optimizing the use of plant extracts as pesticides, like improving their stability, increasing the efficacy against specific pests, and reducing their environmental impact, for which proper studies are needed. However, using them judiciously within limitations is essential while considering their impact on the environment and human health. Overall, Biopesticides/bioinsecticides are very effective alternatives to synthetic insecticides and show effective results in pest management.

The global insecticides market was significant in terms of both revenue and market share. Several variables, such as agricultural practices, the necessity for pest management, technical breakthroughs, governmental regulations, and consumer demand for pest-free environments, have an impact on the growth of the insecticides industry. The expansion of the agriculture industry and the rising use of insecticides also contribute to the greater growth rates seen in emerging nations and developing regions.The size of the global insecticides market reached USD 8.72 billion in 2021 and is expected to expand at a CAGR of 4.6% during the forecast period (2023-2030), reaching USD 13.08 billion by 2030, with a projected value of USD 9.12 billion in 2022.

Declaration of conflict of interest
The authors declare no conflict of interest.

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