Journal of Advanced Scientific Research

Available online through https://sciensage.info

ISSN
0976-9595
Review Article

MODE OF ACTION OF BIOPESTICIDES AGAINST PESTS AND FUTURE PROSPECTS OF BIOPESTICIDES AND NANOBIOPESTICIDES

Nidhi, Saba Mushtaq, Gladys Saji, Vinod Kumar Gupta*

Rapture Biotech International Pvt. Ltd., Noida, Uttar Pradesh, India

**Corresponding author: research.rapturebio@gmail.com*

Received: 07-10-2022; Accepted: 03-12-2022; Published: 31-12-2022

 https://doi.org/10.55218/JASR.2022131101

ABSTRACT

Biopesticides, and nano-biopesticides such as viruses, bacteria, fungi, algae, and nematodes are currently being used in a huge amount and their importance is increasing day by day because pesticides are already created a harmful effects on our health and environment. Due to the chemicals pesticides, diseases are increased in a high rate and food quality is decreased because toxicity level is increased. Biopesticides are best alternative to chemicals pesticides and best results to control pest control programs. The virulence of many biopesticides such as bacteria, fungus, and plant product were tested in laboratory and evaluated under field conditions and successfully approval by government. Biopesticide products are now sold in market for the control of pest and diseases. The aim of biopesticide research is to make these biopesticide products available at field level at a reasonable price and this would become a possible step in the integrated pest management strategy. Moreover, biopesticide research is still going on and in future more products are needed in aspects of bioformulation and areas such as commercialization. This review paper has the important and basic mode of action of major biopesticides in the past. The future prospects for the development of new biopesticides are also discussed such as nano- biopesticides.

Keywords: Biopesticide, Pheromone, Microbial pesticide, Nanobiopesticides.

1. INTRODUCTION

It is irrefutable that world population is increasing very fast and it rich almost 7.7 billion according to report. One of the main problems for human is the lack of quality food due to environmental biotic and abiotic problems like pests, weeds, and diseases [1]. Approx 65,000 types of pests are present and many others types of diseases causing fungus, arthropods are also present in environmen [2]. According to scientists pests almost lower 8-10% production in wheat, 20% in sugarcane, 25% in rice and 50% in cotton.

Therefore, various products were developed in pesticides for prevention of plants from diseases causing pests mainly in developing countries, to overcome food problems. According to a survey, almost 2.3 billion kg of pesticides have been used annually [3]. Different types of pests such as *Altica sylvia* (Blueberry flea beetle), *Aphis gossypii* (Cotton aphid), *Bemisia tabaci* (Sweet potato whitefly), *Acrobasis vaccinia* (Cranberry fruit worm), *Acalitus vaccinia* (Green stink bug) are dependent on crop due to their nutritional requirements [4]. This concern is big for scientists to enhance resistance of crops against pests without harm to crop yields. Pesticides are mixture of chemicals that are used to kill and resist pests.

They are classified into many types such as synthetic pesticides, microbial pesticides, chemicals pesticides, plant- incorporated pesticides, and biochemical pesticides. Chemicals pesticides show good results against pests but they are harmful for environmental and human health. Many pesticides were banned in recent years because they show negative impact on human health and our environment, for example, methyl bromide has been used against soilborne pathogens, and nematodes in many crops but it affects the ozone layer. So, according to Montreal Protocol, it was banned in 2015. Some others pesticides are also banned in some areas due to their effects on food and human health like chloropicrin and dazomet [5].

Biopesticides, also called as biological pesticides are derived from animals, plants, bacteria, and certain minerals. Biopesticides are secondary metabolites of plants, including alkaloids and organic acids. These are classified into three types, *i.e.* microbial biopesticides, botanical biopesticides, and plant-incorporated protectants [6]. Currently, biopesticides have demands all over the world and these products are mainly utilized for the control of disease in plants [7]. Biopesticides are eco-friendly and they do not have any harmfulness to nature. These products are alternative to the chemical pesticides. Microbial pesticides are basically developed by using pathogenic microorganism specific to a target pest, thereby we get easily effective solution against pest problems. Many types of living organisms are used as biopesticides, which are pathogenic for the pests such as biofungicides (Trichoderma, *Pseudomonas fluorescence*), bioherbicides (Phytophthora) and bioinsecticides (*Bacillus thuringiensis*, *Metarhizium anispoliae*, *Buveria bassiania*). Benefits of the biopesticides are cost-effectiveness, costlier but reduced number of applications; biodegradable, low pest resurgence and low residual effect; less harmful on beneficial pests and target specific pest. Compared with chemical pesticides, biopesticides are highly effective and best alternative to synthetic pesticides because these types of pesticides are target specific pest, lower environmental risks, not harmful to beneficial insects and do not create any problems into air and water. In addition, the usage of biopesticides has many others advantages like lower risk to human health and not resistant to target pests [8]. These factors led increasing biopesticides application in control of pest instead of synthetic pesticide all over the world. Biopesticides are usually derived from living organisms such as fungi, bacteria, algae, viruses, nematodes, and protozoa. Since the use of biopesticides, many products have been registered and released in the market and some products have high demand in the agromarket. The development of biopesticide had played a role to replace the chemical pesticide in pest management.

In addition, nanotechnology is the most demanding technology in recent years because nano-particles provides the solution to many environmental problems. This technique has been cost effective, small size and eco friendly behavior. According to recent studies, nanotechnology has been given a effective formulation against pests and also is cost effective as compared to other pesticides [9].

Nano biopesticides have been very effective over the biopesticides, also produce fast results within a few hours while biopesticides are slow in this process. In addition, their small size capability makes them effective when compared with other pesticides and nanobiopesticides easily enter into the plants. Nano biopesticides are synthesized by extracting active pesticidal compound from plants after that blending with nano-particles and insertion into polymer. Active pesticidal compound integrated with nano particles and merged into a compatible vector including polymer, nanosphere, liposomes, and nanofiber [10]. The given data described that nanobiopesticides contain secondary plant metabolites and nanomaterials. In recent years, it was found that biopesticides are eco friendly and effective over pesticides. Recently, many biopesticides have been launched against different pests such as *Trichoderma harzianum, Trichoderma viride* which are used against fungal disease, while *Beauveria bassiania, Bacillus thuringiensis* against insect diseases, neem based nano- biopesticides against many diseases causing insects in plants. Present review explains the importance of nanobiopesticides, and biopesticides for supress and control the pest [11].

2. PESTICIDES

2.1. Uses of pesticides

If we look at agricultural production, it's increased dramatically in 20th century, especially in the United States, to keep up with the burgeoning human population. Population of world has been grown by one billion over the past decade and it will reach almost 9.4 billion to 10 billion by 2050, if current growth rate continues, according to UN reports [12]. In the 20th century, it took a lateral increase in food production is necessary to fulfil food requirements of the world population. This was achieved only through the use of fertilizers and other requirements of agriculture like pesticides in twentieth century. Inorganic phosphate fertilizers were first used in the early 20th century and have steadily gained popularity ever since [13]. Phosphates were used to increase crop yields and have contributed to the unprecedented "green revolution" for agricultural productivity. It was found that a growing world population and increased phosphate production were positively linked during the 20th century, with a relation between these two almost 0.97 for the period 1900-1988 [14].

Pesticides production increased about 11% between 1950 to 2000. Different types of chemicals and insecticides were developed throughout this century to kill these pests. If we compare sales of these types of pesticides, herbicides have been the most demanded group in recent years along with fungicides and insecticides. While herbicide use in Asia has not seen increasing manner but its uses in Western Europe and North America is most according to World Bank and International Food Policy Research Institute data [15].

2.2. Harmfulness of pesticides

In 20th century, ancient synthetic pesticides used for agriculture pest control like DDT (Dichloro-diphenyltrichloroethane) also control human parasites and animal ticks. In place of being prohibited, it is continuously used as a control of home pests and malaria vectors globally [16]. This research elaborates farm workers, and their families following pesticide treatments. Poisoning affects about 3,55,000 individuals annually and is linked to high susceptibility and poor chemical management. The research also conducted to assess the amount of pesticides available in the environment that affects various animals. In affected animals, there have been fish, birds, bees, amphibians, and tiny mammals. It had been also noted that proportion of they were killed and the way they were slaughtered [17].

3. BIOPESTICIDES

Biopesticides are pesticides include active ingredients formed by microorganisms or natural compounds instead of synthetic chemicals. They are also used to control insects and called as biopesticides. Biopesticides are microbial pesticides which are prepared by the using of living microorganisms like bacteria, fungus, and viruses (fig. 1). Biopesticide are divided into three parts like as biochemical pesticides, microbial pesticides and plant incorporated protectants.

Biopesticides uses have been increased dramatically in past years, mainly in developed countries, because these countries placed restrictions for the use of harmful chemicals pesticides organochlorines, carbamates, and organophosphates. Synthetic pesticides are not harmful at the time of uses, but in these pesticides some harmful chemicals are present which contaminate plant crops; a threat to human health, animal welfare, and environmental health. When we talk about biochemical effects, chemical pesticides work by alterations within the signaling system, inhibition of enzymes, pH shifts, disruption of these compounds have the ability to wreck proteins and DNA, additionally also cause of tissue degeneration, and some other effects [18]. Different types of diseases like Parkinson's disease and neuro related diseases, type 2 diabetes, endocrine disruption and many cancers have been occurred because of use of synthetic pesticides,.

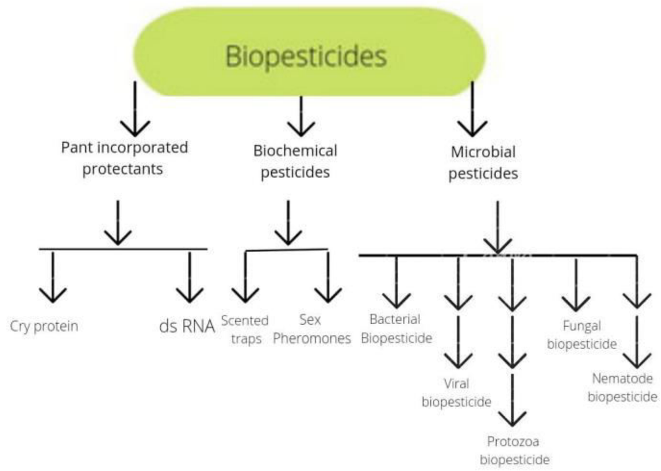

Fig. 1: Types of biopesticides

Natural pesticides offer many benefits over synthetic pesticides, the foremost significance of which is that they are less harmful to the environment and human health. However, this does not mean that they need to be utilized recklessly or inconsiderately for the repercussions of their actions. There are certain products authorized by Government to be used as biopesticides. There are also many others toxic plant species present like microalgae, *Microcystys aeruginosa, Chrysanthemum spp.* and others also these are as similar to cyanide [19].

3.1. Microbial pesticides

Table 1: Bacterial pesticides

Microbial Biopesticide	Target pest	Action	Reference
Beauveria bassiania	Arthropod pests	Fungicide	[20]
Myorthecium vaerrcaria	Ticks	Insecticide	[21]
Alternaria destruens	L sinense	Herbicide	[22]
Chromobacterium *Sp. Panama*	Larval mosquito	Insecticide	[23]
Bacillus thuringiensis	Mosquito	Insecticide	[24]
Metarhizium anispoliae	Lepidopteran	Insecticide	[25]

3.1.1. Bacterial biopesticide

These biopesticides are prepared by the using of living bacterial species like *Bacillus thuringiensis, Pseudomonas flourescence,* etc.

3.1.1.1. Bacillus thuringiensis

In 20th century scientists created a different molecular approach to develop some products of biopesticides. Earlier, several efforts were aimed to make microbial insecticides like *bacillus thuringienesis* which has been used almost from past 49 years [26]. Later, some other developments made by scientists to found a new product such as *Bacillus thuringiensis israelensis (*Bti) and *Bacillus sphaericus 2362* (Bs), which were found effective against mosquito and others dipteran larvae.

Many others species of bacteria were also found by scientists especially *Bacillus, Pseudomonas,* etc., have been established as biopesticides and are used to control insects. Several species of *Bacillus thuringiensis spp. Kurstaki* and *aizawai*, have the highest activity against lepidopteran larval species, *Bacillus thuringiensis tenebrionis,* activity against coleopteran adults and larvae of Colorado potato beetle and *Bacillus thuringiensis japonensis* strain Buibui with activity against soil inhabiting beetles [27].

3.1.1.2. Mode of Action of Bt against pests

Bt produces crystalline proteins and kills few target insects species. The binding of crystalline proteins to insect gut receptor determines the target insect species. Toxicity of Bti and some toxic strains is imputed to the parasporal inclusion bodies which are produced during sporulation time. *Bt* and their species produce different insecticidal crystal proteins. These toxins when ingested by the larvae, damage the gut tissues, leading to gut paralysis. After that, the infected larvae stop feeding and finally they die [28].

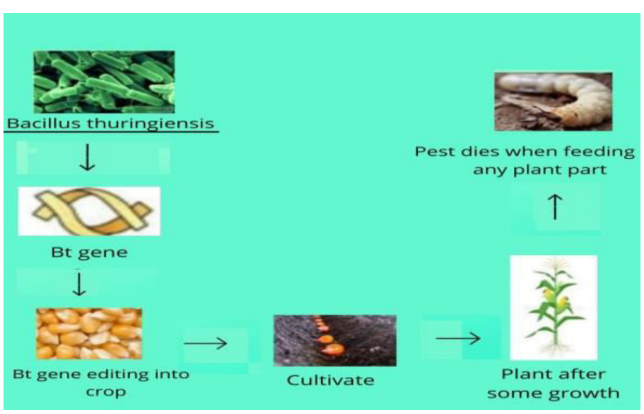

Fig. 2: Mode of Action of *Bacillus thuringiensis*

3.1.2. Fungal biopesticide

3.1.2.1. Metarhizium anispoliae

M. anispoliae is an important entomopathogenic fungus. It is present worldwide in the soil, demonstrating a wide range of insect host species. This was first founded in 1879 by Metschnikoff, under the term *Entomopathora* anispoliae, in the form of wheat cockchafer and later it used for insect pest control worldwide. *Metarhizium* are found in the soil, where conditions permit filamentous growth and production of infectious spores, called conidia, which infect insects after contact. *Metarhizium anispoliae* has the potential to be used as a bioinsecticide agent for controlling the malarial vector species [29].

M. anispoliae strains are isolated from different locations and these are used on a large scale in countries like Brazil where approximate 1,00,000 ha of sugarcanes are treated every year with this bio insecticide for controlling of insects pests [30].

3.1.2.2. Mode of Action of M.anispoliae against pest

A mixture of cuticle-degrading enzyme and mechanical pressure developed by *Metarhizium anisopliae* plays an important role in allowing entering the host through the cuticle. *Metarhizium anisopliae* is known to carry the Mad1 and Mad2 genes that approach the cuticle of the target host and form the reproductive tract when stimulated by external carbon and nitrogen sources (Fig. 3).

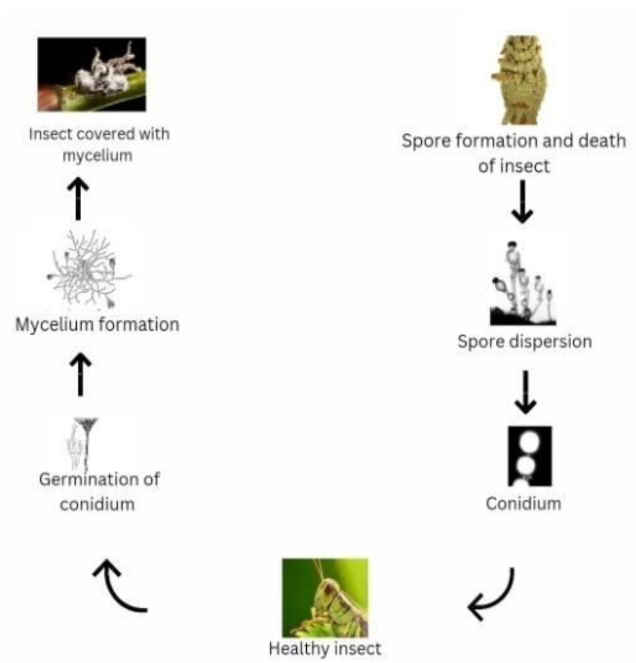

Fig. 3: Mode of action of *Metarhizium anispoliae*

During the germination period, the enzyme trehalase is released. The spores then form an appressorium, where the Mpl1 (myeloproliferative leukemia 1) and ODC1 (Ornithine decarbpxylase 1) genes are identified as responsible for the appressorium formation. After the formation of the appressorium, the fungus enters an osmotic stage that secrets proteins such as carboxypeptidase, subtilisin, chymotrypsin and trypsin. These proteins degrade the target host's procuticle. Inside the host, the fungus colonizes the host and produces destorxin, which suppresses the insect's immune system. The host's blood cells then cover the spores and avoid attacks aimed at thining out the spores. Eventually, sporulation occurs and hyphal extrusion is observed as green mycelia is formed on the carcass of the insect.

3.1.3. Viral biopesticide

3.1.3.1. Baculoviruses

About 600 viruses from 15 families were present as infected insects. These insect viruses are ultramicroscopic, obligatory, intracellular, pathogenic entities. These viruses, which belong to the families Baculoviridae, Polydnaviridae and Ascoviridae are pathogenic to insect and related invertebrates. Most of them belong to the family Baculoviridae, can be used against almost all type of food and textile crops.

Baculoviruses (nuclear polyhedrosis virus NPV and granulosisvirus GV) is primarily associated with the orders of Lepidoptera and Hymenoptera but few are known about isolates from Diptera, Neuroptera, Coleoptera, Trichoptera, Crustacea and mites. These viruses are often genus or species endemic and highly toxic to the host.

Baculoviruses have been reported in over 600 insect species. The Baculoviridae includes alpha baculovirus (scale-specific NPV), betabaculovirus (scale-specific GV), gamma baculovirus (membrane specific NPV), and delta baculovirus (dimension-specific NPV) consists of four genera. Auto graphica californica NPV (AcMNPV) is one of the most intensively studied species [31].

3.1.3.2. Mode of Action of baculovirus against pests

When a larva consumes a virus, the occlusion body dissolves in the acidic stomach fluid and releases viral particles into the gut. The peritrophic membrane lining the midgut then binds viral particles (Fig. 4). The virus's lipoprotein membrane fuses with the plasma membrane of the cells that make up the gut wall and releases nucleocapsids into the cytoplasm. Viral gene expression starts once the nucleotide transfers virus DNA into the cell nucleus. The virus rapidly replicates and invades the host body with viral fragments. Late in the life cycle, these virus particles get occluded. When larvae die, they release a large number of occlusion bodies into the environment, where they spread the infection to new larvae. The larvae grow sluggish and unable to feed themselves after 2-4 days of viral ingestion. The epidermis becomes extremely brittle and prone to rupture at the advanced stage. The larvae wilt and their body parts transform into a fluidized mess of polyhedral and degraded tissue. Infected larvae continuously climb to the substrate's highest point just before they die and cling to it using their prolegs. They hang in a distinctive V form after passing away.

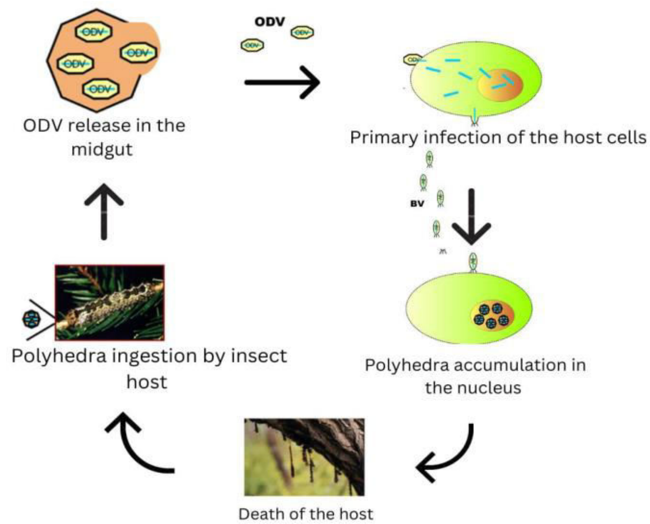

Fig. 4: Mode of action of *baculoviruses*

3.1.4. Nematode biopesticides

Nematodes are in-segmented roundworms, usually microscopic in size. There are many subspecies present in between 1 to 20 million. Some nematodes feed themselves on bacteria, some of plants and some can be animal parasites or insects parasites. Some nematodes are human parasites while some are used for insects control in agriculture such as *entomopathogenic*, insects pathogenic, beneficial nematodesor biological control nematodes. Entomopathogenic nematodes are not parasitic themselves because they do not feed on their host directly, it's symbiotic bacteria. Entomopathogenic nematodes are soil-dwelling organism that occurs naturally in the water film that surrounds soil particles [32]. Nematodes present in nature are *Steinernematidae* and *Heterorhabditidae*. *Steinernematidae* contains insect parasitic bacterium *Xenorhabdus,* while *Heterorhabditidae* possesses *Photorhabdus* nematodes are effective against insects pests.

3.1.4.1. Modes of action of EPNs against pest

Nematodes have different sites for finding their target insects. *Heterorhabditis baceriophora* uses an active cruiser strategy to search their host while *Steinernema carpocapsae* wait for the passing insects (*ambushers)* (Fig. 5). Nematodes rely on chemical cues, temperature cues, and touch or vibration to detect insect host. When they found their host then enter and kill it. Nematodes pass through several life stages. Infective third-stage juveniles in soil enter an insect through natural opening of host such as mouth, anus, and breathing holes. After first step, they enter into insect body cavity and release their bacteria. Then toxins produced by the bacteria kills the insects within a couple of days. These nematodes feed on the liquefying host and the bacteria, and develop into adults, then reproduce and generate their offspring. After that nematodes leave the dead insects and seek a new insect host. Insects killed by *Steinernema tidaen* turn brown while *Heterorhabditis killed* insects turn red.

3.2. Plant based insecticide

Since precedent days, natural compounds from plants were used, more or less efficacious to prevent from insects pests. In nineteenth century, these compounds became scientifically established and widely utilized within the earlier period of 20th century. 15 plants and a few insects have coexisted on the earth. Plants have developed many differences strategies to help themselves from being assaulted by predators. Plant strategy is developing compounds that are highly toxic to insects [33].

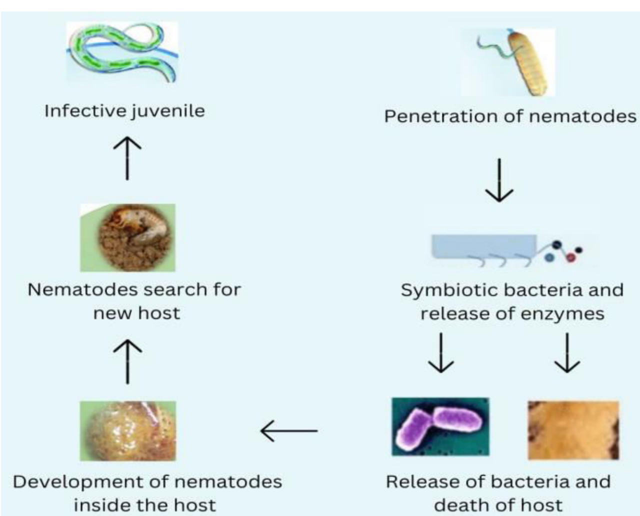

Fig. 5: Mode of action of Nematodes

3.3. Neem

In Asia, neem has a history of use mainly against household and storage pests and against insect pests of crops. A breakthrough within the insecticidal application of neem was attained by scientists [34] who successfully protected the crops from insects by applying them with low concentration of 0.1% seed kernel suspension during a locust invasion. Neem products can be used on crop pest management. Neem product activity has been used against 450-500 insect pest species in several countries around the world, and almost 413 insect pest species are reportedly susceptible at various concentrations [35]. In India, neem has been assessed against 103 species of insect pests, 12 nematodes and many other pathogenic fungi. Scientists have focused on azadirachtin richly from neem seed extracts which act as both strong antifeedants and bug growth regulators. Other biocontrol agents are unaffected by azadirachtin, which only affects the physiological activity of insects. Products are prepared from neem are biodegradable and nontoxic to non-target organisms. In Asian countries, studies have been reported on neem activity alone or in combination with established insecticides and other biocontrol agents of damaging insect pests in agricultural crop system [36].

3.4. Biochemical pesticides

3.4.1. Pheromones

Chemicals produced by insects are called pheromones. These kill different types of pest without effecting human and animals. These pheromones have numerous ion pheromones, alarm pheromones, etc. Pheromone function as sex attractants, permitting individuals to detect and locate mates, while others induce trail following, oviposition, and aggregation in other congeners. In monitoring and controlling agricultural pest populations, pheromones have best as compared to synthetic pesticides because they are less toxic, almost 1,600 pheromones and sex attractants have been reported. In the recent years, there have been present different types of insect pheromones and also new opportunities have arisen for saving our environment and to explore the use of semiochemicals in managing insect pest problems. They can be applied in integrated control in combination with other practices [37].

Pheromones and other semiochemicals are being used on millions of hectares to control pests. The use of pheromones for pest monitoring has a number of benefits, including lower costs, specificity, simplicity, and high sensitivity. The US EPA has certified 30 mating-disruption pheromone based products as biocontrol agents for lepidopteran pest species that can harm agriculture.

4. NANO-BIOPSTICIDES

From 1959 to 1960, developments in nanotechnology and nanoscience have been made, for the role of nano-particles to using for biomedical applications. Nanoparticles are found abundantly in plants like as algae in the form of superoxide nano-particles. Nano-particles are synthesized by physical, chemical, and biological methods [38]. Nano-particles have different applications in the field of agriculture, medical, pharmaceutical, and pest management sectors. Nano biopesticides are very useful instead of other pesticides due to their tiny size, stability, better solubility, mobility, and decreased toxicity. To overcome these issues, pesticides with formulation of nano-particles are used. Nano biopesticides can be tested against a specific pest to check their efficiency in different crops. Nanobiopesticides have specific activities against some pests like pupicidial activity, larvicidal activity, and anti-feeding activity etc.

4.1. Mechanism of action of nano-biopesticides

There are different types of biopesticides with different mode of action such as sabdilla, pyrethrum, azadirachtin, and fluoroacetate that show different action against pests. For example, the alkaloid toxin of sabdillaca used loss of nerve cell membrane. It's found that sabdilla could kill most of insects immediately after its use [39]. Although pyrethrins are not poisonous, they instantly kill insects. For humans and animals it's not toxic. Pyrethrins altering the process of sodium and potassium ion exchange in insects nerve fibres, it's causes inhibition of the transmission of nerve impulses. While azadirachtin have antifeedant activity and it causes reduced food consumption instead of control. It was reported that inhibition of food behavior azadirachtin dose from stimulation of deterrent receptors was coupled with sugar receptors that lead to food restrictions, starvation, and bad nutrition. Various studies have been demonstrated the weight loss in some insects such as *Spodoptera eridania, Periplaneta Americana* and *Helicoverpa armigera* etc [40]. In plant extracts and in some oils a range of compounds are present that may interact with insects nervous system and coordination and resulting death of insects by disrupt their life cycle.

5. CONCLUSION

Biopesticides are being used from decades for controlling of pests and pathogens which are harmful for crops. Scientific and technological interventions related to the development of biopesticides are not so much efficient as proven by lack of knowledge of mechanisms at ground level, and there is no penetration of the pest control market in India. If we talk about the global use of biopesticides in crops, it has increased fairly, mainly in the European and American region. This is clear from the report that overall half of the globally produced biopesticides are being used by the USA, Canada, and by the European Union. Similarly, directives for microbial biocontrol pests in EU and USA are also less complex and flexible as compared to Indian system. There is need of some steps from the authorities in India for promoting the biopesticides for research, production and sensitizing the farmers. Government and private sectors will have to come together and work with farmers at the ground level for promoting biopesticides and nanopesticides. Government's policy and support is need for better R & D infrastructure, ease of regulations and assuring support to farmers for using biological products. Chemical pesticides have a bad impact on the environment as well as soil fertility, it is necessary for all of us to shift towards biopesticides and nanopesticides. If we are not going towards these products, then it is quickly realized to us that soil fertility is going towards the low concentration of nutrients and polluted by synthetic pesticides. So, it is our responsibility to make our agro-ecosystems sustainable for food security in the future.

Conflicts of interest

None declared

6. REFERENCES

1. Sinha K, Ghosh J, SilPC. *New Pesticides of Soil Sensers:* Elsevier, 2017; 47-79.
2. Berini F, Katz C, Gruzdev N, Casartelli M, Tettamanti G, Marinelli F. *Biotechnology* Advances,2018;**36(3)**:818- 838.
3. Rajendran G, Islam R. *CABI Case Studies*, 2017; **19**:145-152.
4. Chowański S, Adamski Z, Marciniak P, Rosiński G, Büyükgüzel E. *Toxins*, 2016; **8(3)**:60-69.
5. Huang X, Zhao J, Zhou X, Han Y, Zhang J, Cai Z. *European Journal of Soil* Science, 2019; **70(3)**:518-529.

6. Mathew IL, Singh D, Singh R, Tripathi C. *Biolife*, 2014;**2(1)**:348-362.
7. Kumar A, Dhananjaya PS, Tyagi M. *Journal of Microbiology and Biotechnology*, 2003; **13(1)**:50-56.
8. Kumar S. *Journal of Biofertilizerand Biopesticides*, 2012; **3**:4.
9. Chaloupka K, Malam Y, Seifalian AM. *Trends in* Biotechnology, 2010; **28(11)**:580-588.
10. Ragaei M. *International Journal of Environmental Science and* Technology, 2014; **3(2)**:528-545.
11. Mandal BK. *London, United Kingdom: Elsevier*, 2019; 281-302.
12. Desa U. *World population prospects: ESA/P/WP*, 2412015.
13. Gilland B. *Science Progress,* 2015; **98(4)**:379-390.
14. Hendrix CS. *Peterson Institute for International Economics*, 2011; **4(11-18)**:1-12.
15. Carvalho F. *Food and Energy Security*, 2017; **6**:48-60.
16. Taylor MD, Klaine SJ, Carvalho F, Barcelo D, Everaarts J. *London, UK: CRC Press*, 2002.
17. Paoli D, Giannandrea F, Gallo M, Turci R, Cattaruzza M. *Journal of Endocrinological Investigation*, 2015; **38(7)**:745-752.
18. Costa JAV, Freitas BCB, Cruz CG, Silveira J, Morais MG. *Journal of Environmental Science and* Health, 2019; **54(5)**:366-375.
19. Kumar A, Dhananjaya PS, Tyagi M. *Journal of Microbiology and* Biotechnology, 2003; **13(1)**:50-56.
20. Dara SK, Dara SS, Dara SS. *UCANR eJournal Strawberries and Vegetables*, 2016; 19.
21. Habeeb SM, Ashry HM, Saad MM. *J Parasitic Dis*, 2017; **41(1)**:268–73.
22. Yang Q, Ma X, Chen T, Liang W. *Plant Disease*, 2019; **103(11)**:29-59.
23. Caragata EP, Otero LM, Carlson JS, Dizaji NB, Dimopoulos G. *Appl Environ Mictobiol*, 2020; **86(11)**:e00240.
24. Poopathi S, Abidha S.*J PhysiolPathophysiol*, 2010; **1(3)**:22–38.
25. Aw KMS, Hue S. *Journal of fungi*, 2017; **3(2)**:30.
26. Gelernter W, Schwab GE. *Wiley, Chichester,* 1993; 89–124.
27. Copping LG, MennJJ. *Pest Manag Sci*, 2000; **56**:651–676.
28. Betz FS, Hammond BG, Fuchs RL. *Regul Toxicol Pharmacol*, 2000; **32**:156–173.
29. Mnyone LL, Koenraadt CJM, Lyimo IN, Mpingwa MW, Takken W, Russell TL. *Parasite Vectors,* 2010; **3**:80.
30. Faria MR. *Biotecnol Cienc Desenvolvimento*, 2001; **22**:18–21.
31. Cory JS.*Crop* Protection, 2000; **19**:779–785.
32. Peters A. *Biocontrol Sci Technol*, 1996; **6**:389–402.
33. Nisha S, Revathi K, Chandrasekaran R, Kirubakaran SA, Sathish-Narayanan S et al. *PhysiolMol Plant Pathol,* 2012; **80**:1–9.
34. Pradhan S, Jotwani MG, Rai BK. *Indian Farm*, 1962; **12**:7–11.
35. Schmutterer H, Singh RP. *VCH, Weinheim,* 1995; 325–326.
36. Abdul Kareem A, Saxena RC, Justo HD Jr. *Int Rice Res Newsl*, 1987; **12**:28–29.
37. Reddy GVP, Guerrero A. *Trends Plant Sci,* 2004; **9**:253–261.
38. Lade BD, GogleDP. *Plant Protection*, 2019; 169-189.