



Biopesticides and biorationals: As alternative and effective strategies in agricultural pest management: An overview

Samya Chakraborty¹, Salil K Gupta²

¹ Department of Zoology, Barasat Government College, Kolkata, West Bengal, India

² Department of Medicinal Plant Research, Post Graduate Residential College, Ramakrishna Mission, Narendrapur, Kolkata, West Bengal, India

Abstract

Biopesticides are natural products which can control agricultural pests including fungi, weeds, bacteria, viruses etc. Biopesticides may be plant extracts/ pathogens/ oils (vegetative oil, fish oil, mineral oil, etc), insects, mites, nematodes, rodents. These are ecofriendly, safe and best alternatives of chemical pesticides and hence used in IPM. Biorationals are chemical compounds, non-disruptive, innocuous and target specific. As of now, chemical pesticides always dominate in pest management system around the world. This review discusses the current status, future scope and advantages and disadvantages for use of Biopesticides and Biorationals.

Keywords: Biopesticides, biorationals, pests, IPM, ecofriendly, cost effective, antifeedant

Introduction

General Introduction of Biopesticides and Biorationals:

Agricultural pests like insects, mites, nematodes, and pathogens affect crop quality and quantity. Since 1960s, farmers have used chemical pesticides for pest control which, despite reducing pest population have negative impact on human health and agriculture. The European Union suggests biopesticides as the best alternative as these are derived from biological organisms or natural products. Biopesticides are effective, target-specific, and environmentally safe. They are integral component of Integrated Pest Management (IPM), a sustainable approach for improving crop production. Current research focuses on enhancing the use of biopesticides to replace chemical pesticides in IPM plans, which combine chemical, physical, biological, and mechanical pest control. Challenges before us include marketing of biopesticides and improving their stability and residual action. Additionally, for 50 years, biorational pesticides, which are non-toxic to humans and animals, have been included in pest control method. This review summarizes the current status of biopesticides and biorationals in agricultural pest management and their role in IPM strategies.

History of using Biopesticides / Biorationals

Historical Background of Biopesticides

The historical background of biopesticides dates back to the 17th century when nicotine plant extract was used against plum beetles. In 1835, Agostino Bassi demonstrated the use of the fungus *Beauveria bassiana* as a biological control agent for control of silkworms. In the early 19th century, plant-based mineral oils were identified as protectants. In the *Bacillus thuringiensis* (Bt) spores for biocontrols. In 1901, Shigetane Ishiwata isolated Bt from diseased silkworms, and in 1911, Bt was classified as a biological insecticide. The first commercial Bt product, Sporeine, was developed in France in 1938. During 1917, the US Navy used Pyrethrum extract with kerosene to control houseflies and mosquitoes. In 1924, Swiss researchers identified pyrethrum's insecticidal properties due to its esters

Pyrethrin I and II. Under India's Insecticide Act of 1968, twelve types of biopesticides have been registered so far.

1. Neem Based Biopesticides
2. *Bacillus thuringiensis*
3. NPV (Nuclear Polyhedrosis Virus)
4. *Trichoderma* sp.etc.

Historical Background of Biorationals

Carl Djerassi initially used the term "biorationals" for pheromones, insect hormones, and hormone antagonists. The Environmental Protection Agency considers it synonymous with biopesticides. Neem, as antifeedant, has been used since the 12th or 13th centuries and also served as medicine. *Sabadilla* gained prominence in the 16th century, especially during WWII, alongside other botanicals like pyrethrum and rotenone. Allelochemicals, another type of biorationals, were introduced by Hans Molisch in 1937. The first biorational allelochemic was produced in 1974. Juvenile Hormone, discovered by Wigglesworth in 1934, is now used as a metamorphosis regulator. GABA, introduced in 1950, inhibits insect nerve impulses. Kaolin clay, used in China for over 2000 years, controls insects covers Various biopesticides and biorationals from past to present and their role in sustainable pest control.

Biopesticides

What is Biopesticides?

Biopesticides are based on living organisms or natural elements that control agricultural pests including bacteria, fungi, weeds, viruses, insects, mites, nematodes etc. (Samada and Tambunan, 2020) ^[18]

Or, Biopesticides are developed from naturally occurring living organisms such as animals, plants and microorganisms that can control serious plant damaging insect pests by their nontoxic ecofriendly mode of actions. (Nathan and Sengottayan, 2015)

According to, TNAU Agritech Portal Farm Enterprises stated: - "Biopesticides are living organisms which can intervene the life cycle of insect pests in such a way that the crop damage is minimized".

As per, The U.S. Environmental Protection Agency, the Biopesticides "are certain types of pesticides derived from such natural materials as animals, plants, bacteria, and certain minerals."

A Biopesticide would be an ideal Biopesticides when,

- It is safe to use
- It is eco-friendly in nature
- Non-toxic to human, animals and other beneficial insects
- Target specific
- Easily biodegradable
- Highly effective
- Easily decreases the pest growth, development.
- Production cost lower
- Maintains Sustainability in Agro-ecosystems.

According to USDA, - "Biopesticides are the naturally occurring substances that control pests and microorganisms."

Types of Biopesticides

▪ Plant Extracts

It is also called Green Pesticides. Since ancient period, natural compounds from plants were used more or less efficaciously to protect the crops from insect pests. In nineteenth Century, these compounds became scientifically established and widely utilized in the earlier period of Twentieth Centuries. Plants and insects co-existed over several millions of years, and that allowed coevolution.

▪ Neem Extract

It is a very much important Ayurvedic medicinal plant and is used to make medicines. It produces secondary metabolites that act as repellents. In Asia, Neem has an extensive use against household and storage pests. The production of Neem seed kernel extractions was used against locust attack. (Senthil-Nathan and Sengottayan, 2015)

Indian Neem Tree (*Azadirachta Indica*) is one of the most important liminoid producing plants.

Main Insecticidal components of Neem

Azadirachtin compounds: It is a highly oxidized tetranortriterpenoid which boasts a plethora of oxygen-bearing functional groups, including enol ether, acetal, hemiacetal, tetra-substituted epoxide and a variety of carboxylic esters.

Procedure of production of Neem Extracts

For preparation of the Neem seed kernel extracts in 100 lit. Of 5% NKSE sol., the following procedure may be followed:

1. 5 kg neem seed kernel should be grinded to form powder and soaked overnight with 10 lit. of water.
2. Periodically it should be stirred with wooden rod.
3. Then it is filtered with double layered Muslin Cloth and 1% detergent is used to make the spray solutions.
4. Then it is ready for use in agriculture.

Mode of Actions: Azadirachtin interferes with a wide variety of insect pathways.

- The substance acts as an Insect Growth Regulators (IGR) and Stomach poison. It antagonizes both Ecdysteroids (mainly 20E) and JH activities by reducing secretion of PTTH and allatropins from the Corpus cardiacum complex. This neuroendocrine disruption reduces pupation. It also causes degeneration of other neuroendocrine glands.
- The substance disrupts reproductive functions, going as far as sterility in some insects. This is partially due to the aforementioned neuroendocrine disruption surrounding 20E and JH. It could also affect yolk protein and vitellogenin synthesis. It also reduces mating success by deterrence.
- The substance also deters feeding, making it an antifeedant. It disrupts the sense of smell to the point that some insects would rather starve than eat Azadirachtin-based food. If the insect ingests the compound, the substance further inhibits digestive enzymes and could leave an aversive taste memory by activating dopaminergic neurons.
- Azadirachtin additionally has a long list of cellular and molecular targets. It up-regulates p53, disrupts protein synthesis possibly through binding to Hsp60, and changes the expression of many other pathways.

Some successful results with Neem Extract

1. In Indian agriculture, neem treatment is very efficient and effective against insect species like green leaf hopper, yellow stem borer, Rice gall midges, Grasshopper etc. (Dhaiwal *et al.* 1996, Nanda *et al.* 1996)
2. According to some, the procedure to prepare extract is very simple.
3. Sugarcane leaf hopper, *Pyrilla sp.* and Shoot borer can be easily evaded by neem extract.
4. It gives its special potentiality against 103 species of insects and 12 species of nematodes in Indian Agriculture [Singh, (1996, 2000), Saxena (1998), Singh & Raheja (1996)]
5. It is effective for *Sitophilus oryzae*. Farmers used this extract for sterilizing the store room.

▪ *Melia azedarach* extracts

Melia azedarach or chinaberry plants are used in pest control. It is also known as pride of India or white cedar. The plant is 7- 12 meters long and flowers are small, have fragrance and fruit is a drupe, marble sized.

Main Insecticidal Component of *Melia sp.*: Azadirachtin related product Tetranortriterpenoid compounds. It is a Liminoid compounds (Cannolly *et al.* 1983)

Procedure of *Melia sp.* extract production: For production of *Melia sp.* extract, fruits and leaves are used. Procedure of extract production is same as described previously (Neem).

Mode of Actions: Tetranortriterpenoids performs in various ways like;

- **Insecticidal:** It has insecticidal properties.
- **Growth regulator:** These extracts are used to regulate the growth or moulting of pest insects.
- **Antifeedant:** Antifeedant are those that deter the insects to feed on the crop and prevent damage. *Melia* sp. has special toxic properties for insect attack prevention.
- **Behavioral effects:** It causes behavior changes in insect and also causes the growth retardation.

Some Successful results with *Melia* extracts:

1. Biopesticides from *M. azedarach* extract is used to produce microencapsulation and supercritical CO₂ via spray drying with a blend of cheese with gum Arabic. It reduces the pest population, increase the yield by about 3.84% than normal.
2. After introduction two spotted spider mite (*Tetranychus* sp.) destructive herbivorous arachnids are totally reduced from crop fields.

(Champagne *et al.* 1989; Schmutterer, 1990; Senthil-Nathan and Kalaivani *et al.* 2005, 2006) (Cannolly *et al.* 1983; Saxena *et al.* 1984; Ascher *et al.* 1995)

▪ **Tulsi Extracts (*Ocimum sanctum*)**

Tulsi Plant (*Ocimum sanctum*) has been widely available in southwest Asia, Philippines, India, and Sri Lanka and has been considered as a holy plant in many parts of India with attractive aromatic smell (Shikha and Kashyap, 2023). Especially among tribals, the Tulsi plant has been used as medicines for treatment of cold, cough, fever, and urinary tract infections. (Dey *et al.*, 2021; Kumar *et al.*, 2021). Apart from medicinal applications, the Tulsi leaf extract has been proved to have insecticidal properties (Ojewumi *et al.*, 2021).

Main Insecticidal Component of Tulsi: Caryophyllene (Yazdanian *et al.*, 2022).

Procedure of Tulsi plant extract production: Procedure of extract production is same as described earlier.

Mode of Actions: Same as mentioned for previous plant extracts.

Some Successful results with Tulsi extracts

1. It can easily decrease the mosquito's populations in houses (Singh *et al.*, 2008).
2. It can deter sucking insect pests in agriculture (Ghodake *et al.*, 2014)

▪ **Nishinda Extract (*Vitex negundo*)**

Nishinda plant (*Vitexnegundo*), Nishinda plant is an important medicinal plant. It is also called Chinese chaste tree or Horshoevitex. It has been widely available in the south eastern and southern countries. It is important for folk medicine preparation.

Main Insecticidal Component of Nishinda: Nishindine.

Procedure of Nishinda plant extract production:

Procedure of extract production is same as described earlier (Neem).

Mode of Actions: Same as mentioned earlier.

Some successful results with Nishinda extracts

1. In Chhattisgarh, in the olden days, it was common practice to burn dried leaves of *Vitex negundo* in rice fields in order to repel harmful insects. (Ahuja *et al.*, 2008)
2. It can deter leaf beetle, tomato fruit borer, cutworm etc. (Narayanasamy, 2006)
3. It can also prevent the attack of aphids, mealybugs and thrips.
4. It can also deter Uzifly (Chinnamma, 2017) ^[2]

▪ **Parthenium Extracts (*Parthenium* sp.)**

Parthenium Plant (*Parthenium* sp.), *Parthenium* plant is a North American plant.

Main Insecticidal Component of Parthenium: Parthenin (Datta and Saxena, 2001)

Procedure of Parthenium plant extract preparation:

Procedure of extract preparation same as described earlier (Neem).

Mode of Actions: Same as mentioned earlier.

Some Successful results with Parthenium extracts

1. It can prevent the attack of aphids, mealybugs and thrips attack.
2. It can deter Lepidopteran pest from soybean field (Ullah *et al.*, 2022) ^[25].

▪ **Lantana camara Extracts (*Lantana camara*)**

Lantana camara, is a native species to tropical America. It is an invasive weed and now has spread across the world. It has lot of bioactive molecules in the leaves, roots, stem, flowers, etc. It has insecticidal properties against crop and household pests.

Main Insecticidal Component of Parthenium: There are many insecticidal compounds like α -Copaene, Germacrene D&B, α -Cubebene, β -Elemene, α -Guaiene, α -humulene, Aromadendrene, β -Selinene, α -Selinene, Caryophyllene oxide, Nerolidol, Spathulenol and Delta-Cadinene. All are sesquiterpenoids, Triterpenoids and alkaloids compounds. (Snehasish *et al.*, 2021)

Procedure of Lantana plant extract production:

Procedure of extract production is same as described previous (Neem).

Mode of Actions: Same as mentioned earlier.

Some Successful results with Lantana extracts

1. It can prevent the attack of aphids, mealybugs and Thrips attack (Routra *et al.*, 2021) ^[17]
2. It can repel mosquitoes, house hold and stored grain pests. (Snehasish *et al.*, 2021)

▪ **Karanja Extracts (*Pongamia glabra*)**

Karanja plant (*Pongamia glabra*), Karanja is a medium sized deciduous plant and is evergreen in nature. It has insecticidal properties. It is available in India, Srilanka, Pakistan. It is also called as Indian beech. (Dhillon and Singh, 2002)

Main Insecticidal Component of Karanja: Karanjin.

Procedure of Karanja plant extract production: Same as described earlier.

Mode of Actions: Same as described earlier.

Some Successful results with Karanja extracts

1. It acts as a larvicide and potential oviposition deterrent of insects. (Kumar and Singh, 2002)
2. It is effective against aphids, mosquitoes and locust attack.

▪ **Ginger Extracts (*Zingiber officinale*)**

Zingiber officinale is a flowering plant whose rhizome is called ginger and is widely used as a spice. It also has medicinal and pesticidal properties.

Main Insecticidal Component of Ginger: Zingerone, Gingerol, Shogaol and Paradol.

Procedure of Ginger plant extract preparation

1. First the ginger rhizome is cut and crushed to make a paste.
2. Then Distilled water is added at room temp.
3. After filtering it the pesticide is prepared.

Mode of Actions: Same as mentioned earlier.

Some Successful results with Ginger extracts

1. It can prevent the attack of *C. maculatus* (Amuji *et al.*, 2012) [7].
2. It can repel mosquitoes and house hold and stored grain pests

▪ **Garlic Extracts (*Allium sativum*)**

Allium sativum is a bulbous plant, widely used a culinary spice. It has strong aroma and taste. It has medicinal and insecticidal properties.

Main Insecticidal Component of Garlic: Allicin, Diallyl disulphide, Ajoene, Diallyltrisulfide.

Procedure of Garlic plant extract preparation: Same as in ginger.

Mode of Actions: Same as mentioned earlier.

Some Successful results with Garlic extracts: It has agricultural pesticidal properties. (Rinaldi *et al.*, 2019) [16]

▪ **Onion Extracts (*Allium cepa*): -**

Allium cepa is also a bulbous plant, widely used a culinary spice. It has strong aroma and taste. It has medicinal and insecticidal properties.

Main Insecticidal Component of Onion: Allicin, Ajoene.

Procedure of Onion plant extract preparation: Same as in Ginger.

Mode of Actions: -Same as mentioned earlier.

Some Successful results with Onion extracts

1. It successfully evades Armyworm (*Spodoptera sp.*) from corn field in greenhouse condition. (Munyore *et al.*, 2020) [14]

▪ **Turmeric Extracts (*Curcuma longa*)**

Curcuma longa is also a medicinal plant. It has Vit – D and Natural color. It also has insecticidal properties.

Main Insecticidal Component of Turmeric: Curcumin, Turmerone, Cineole, Zingiberene

Procedure of Turmeric plant extract preparation: Same as in Ginger.

Mode of Actions: Same as mentioned earlier.

Some Successful results with Turmeric extracts

1. It Successfully evades mosquitoes and agricultural pest (Damalas, 2011) [4]

▪ **Oils**

Oils are another type of biopesticides that are produced by plant mainly from stem, root, leaves, seeds, etc. Oils are terpenoids type materials that help to control insect populations. Some are volatile compounds and act as insect growthregulators, antifeedant and deterrents. Various types of oils are used for pesticidal purpose: -

- **Vegetative Oils:** Vegetative oils are inexpensive and essential insecticides. It is the convenient way to prevent sucking insects on leaves. It is sprayed as mists.

Mode of Action

- **Systemic poison:** - Oils can block the spiracles of insects so cause death of insect.
- **Antifeedant:** - Due to anti-insecticidal properties, oils help to deter or prevent insect feeding on leaves.
- **Target specificity:** - It only kills targeted pest not the beneficial insects.

Table 1

Examples of Vegetative Oils	Brief Descriptions
Neem Seed Kernel Oil	Extracted from Neem seed kernel, has insecticidal properties (Elanchezhyan and Bojan, 2015) (Senthil-Nathan andSengottayan, 2015)
Cotton Seed Oil	Extracted from Cotton seed, has insect repelling properties.
Mustard Oil	It is the important oil, acts as antifeedant or deterrent, effective against mosquitoes. It is also used in agricultural field to deter <i>Sitophilus oryzae</i> and <i>Callosobruchus chinensis</i> . (Kim <i>et al.</i> 2001)

Canola Oil	It is produced from leaves and act as irritant. It also acts as important fungicide.
Palm Kernel Oil	Produced from Palm kernel, acts as insect repellents. (Asib <i>et al.</i> , 2021)
Soybean Oil	Extracted from soybean seed, has insect repelling properties. (Lopez <i>et al.</i> , 2006)

- **Mineral Oils:** Mineral oils are mainly HMO Oils or Petroleum oil. Those are produced from preserved dead bodies of animals buried in soil. These oils are expensive, sometimes hazardous. These are mainly used to deter insects. Paraffin oils are also used.

Mode of Action

- **Nerve Poison:** It affects the nervous system of insects.
- **Respiratory Poison:** It affects respiration in insects. It blocks the spiracles of insects.

Table 2

Example of Mineral Oils	Brief Descriptions
HMO or Petroleum Oil	Petroleum oil is produced from dead buried animals. This is much more expensive, used as insect deterrents. (Martin, 1935) (Riley, 1891 & 1892) (Agnello, 2002) (Baliota and Athanassiou, 2022)
Paraffin Oil	Paraffin Oil is another mineral oil also used as insect repellents but it is also expensive, hazardous and is flammable. (Baliota and Athanassiou, 2022) (Swingle and Snapp, 1931)
Tar oil	Tar Oil is one type of oil that when is mixed with nicotine can deter thrips, aphids etc. (Baliota and Athanassiou, 2022)

- **Essential Oils:** Essential oils are produced by many weeds, plants, grasses etc.

Mode of Action

- **Mental retardation of insects:** The oils inhibit insects' mental abilities while drying out their exoskeleton.
- **Larvicidal properties:** It is lethal to the larvae. Many insects' larvae die due to use of essential oil.

Table 3

Examples of Essential oils	Brief Descriptions
Cinnamon Oil	Produced from dried inner bark of the shoots of the plant, has insect deterrent activity. (Lopez <i>et al.</i> , 2018)
Clove Oil	Clove oil is best essential oil produced from clove seed, has insect repellent activity against Bed Bug. (Andrews <i>et al.</i> , 2021)
Lavender Oil	Lavender oil is another essential oil effective for fleas, bugs and Beetles. It is the best Insect repellent. (Kulma <i>et al.</i> , 2017)
Cedarwood Oil	Cedarwood oil is important insect repellents effective against biting moths, beetles etc. (Sharma &Goel, 2017)
Eucalyptus Oil	Eucalyptus leaves are important essential oil producer having insect repellent properties (Kulma <i>et al.</i> , 2017)
Peppermint Oil	It is important oil produced from mentha plant leaves, has insecticidal activities. (Shrivastava, 2009)
Lemon Grass Oil	Lemon Grass leaves are important sources of essential oil, has much more efficacy against mosquitoes and aphids. (Shrivastava, 2009)
Neem Oil	Extracted from Neem seed kernel, has insecticidal properties (Elanchezhyan and Bojan, 2015) (Senthil-Nathan andSengottayan, 2015)
Orange Oil	Orange leaves are important essential oil producer having insect repellent properties (Kulma <i>et al.</i> , 2017)
Citronella Oil	Citronella leaves are important sources of essential oil, have much more efficacy against mosquitoes and aphids. (Shrivastava, 2009)
Rosemary Oil	It is important oil produced from plants and flower leaves have insecticidal activities. (Shrivastava, 2009)
Oregano Oil	It is the important essential oils effective for stored grain pests, locust, mosquitoes, beetles etc. (Alizadeh, 2017)
Thyme Oil	These leaves are important in oil production, has insecticidal activities. (Shrivastava, 2009)

Animal Oils: Animal oils are lipids that are derived from animals. It is very expensive, used to deter insects from particular crop field.

Mode of Action

- **Nerve Poison:** It affects the nervous system of insects.
- **Respiratory Poison:** It affects respiration in insects. It blocks the spiracles of insects.
- **Systemic Poison:** It blocks the spiracles of insect cuticle. Due to breathing problem, insects easily die.

Table 4

Examples of Animal oils	Brief Descriptions
Fish Oil	Fish oil is derived from the tissues of oily fish. It contains Insect repellence capability.

Pathogens

Pathogens are the microorganisms and include fungi, virus, bacteria, nematodes, protozoa, and spirochaetes, etc. These organisms produce disease to the target insects. They are unicellular or multicellular. They are also referred to as infectious agents.

Bacteria

Since 1980 and upto now, various molecular studies have been done to develop market acceptable Biopesticides. ‘Bt’ Toxins has been used for the last 40 years. This is produced by *Bacillus thuringiensis*. Another microbial product, ‘Bs’ toxin is used to deter mosquitoes. ‘Bti’ toxin was first discovered as effective toxin against mosquito larvae.

Mode of Action

Most ‘Bt’ toxins are highly effective to Lepidopteran insects. These toxins are also effective to Colorado Potato Beetles, Black fly, Mosquitoes etc.

- ‘Bt’ produces crystalline proteins.
- These crystals are non-toxic but after ingestion by insects, it goes to the midgut and bind with midgut receptor.
- Then it activates G protein coupled receptor pathway by formation of Toxin monomer to oligomer.

- Protein kinase – A increases due to intracellular cAMP production increases.
- It mediates cell death pathway. So, apoptosis of cell occurs.
- Sometimes by binding with GPI anchored and Cadherin proteins, it increases Pore formation. So, Osmosis occurs. Therefore, these lead to cell death.

It causes gut paralysis after ingestion. Midgut epithelium impairment is caused by another bacterio-toxin produced by Rhizobacteria. These are all available commercially.

Examples of Pathogenic Bacteria

1. BT Toxins – *Baccillus thuringiensis*
2. BS Toxins – *Baccillus sphaericus*
3. Exotoxins – *Pseudomonus* sp.

Table 5

Examples of Pathogenic Bacteria	Brief Descriptions
<i>Baccilus sphaericus</i>	It is one type of Gram – positive bacteria. It is temperature, UV-Light resistant. It has an important role in preventing insect pests attack. (Senthil-Nathan andSengottayan, 2015)
<i>Pseudomonus</i> sp.	<i>Pseudomonus</i> sp. is an important Biopesticide, can destroy the fungal pathogens to prevent the diseases of plants. (Anderson and Kim, 2018)
<i>Baccilus thuringiensis</i>	It is also one type of Gram – positive bacteria. It is temperature, UV-Light resistant. It has an important role in preventing insect pests attack. (Senthil-Nathan andSengottayan, 2015)

Fungi

Fungi are another type of pathogens that effect on the development of insects. *Metarhizium anisopliae* is an essential entomopathogenic fungus, propagates worldwide in the soil, demonstrating a wide range of host species. Metschnikoff first discovered *Entomophthora anisopliae* as a pathogen against wheat cockchafer, and later was termed as *M. anisopliae*.

Mode of Action

Under natural condition, *Metarhizium sp.* are found in the soil, where moist conditions permit the growth through conidia.

It acts on larvae as: -

1. It attaches within insect cuticular wall by conidium.
 2. Then conidium germination occurs and hyphae formation begins through penetrating the cuticle.
 3. Then conidia producing conidiophore develops and infected cells of insect body begin to apoptosis.
 4. All spores and hyphae spread through the body of larvae throughout Haemolymph and insect dies.
- It is very much safe, eco-friendly and target specific.

Examples of Pathogenic Fungus

1. *Metarhizium anisopliae*
2. *Lecanicillium lecanii*
3. *Beauveria bassiana*

Table 6

Examples of Pathogenic Fungus	Brief Descriptions
<i>Metarhizium anisopliae</i>	Entomopathogenic fungus acts on insect pests, mites and nematodes also. (Senthil-Nathan andSengottayan, 2015)
<i>Beauveria bassiana</i>	It is an Entomopathogenic fungus acts as a parasite on various arthropod species, causing white muscardine disease; (Muscarin and Jaronski,2016)
<i>Lecanicillium lecanii</i>	It is widely used in agriculture as insect pest protectants. It has been proved that –this fungus is much more effective on tea thrips. (Subramaniam <i>et al.</i> , 2021)

Virus

Viruses are the important pathogens that cause diseases in host insects. For insect control we always use Baculoviruses. These are the double stranded DNA Viruses present in arthropods, mainly in insects. Baculoviruses are mainly pathogenic against numerous serious pests. Application is still limited in agriculture and horticulture.

Mode of Action

1. Baculoviruses are usually ingested by lepidopteran insect larvae and initiate infections.
2. After ingestion, these viruses go to midgut and from their spread throughout body.

3. Two groups of Baculoviruses present Nuclear Polyhedrosis virus (NPVs) and Granulovirus (GVs).
4. In NPVs, occlusion bodies comprise numerous virus particles but in GV's ordinarily contains just one virus particle. They easily are embedded in protein matrix of insects midgut occlusion bodies which help them to live outside the host.
5. Recent studies reveal that Baculoviruses are species specific and easily be genetically modified.
6. IPM management proposed that – It will be used in small scale.

Table 7

Examples of Pathogenic Viruses	Brief Descriptions
Nuclear Polyhedrosis virus (NPVs) <ul style="list-style-type: none"> ▪ (<i>Autographa californica</i> – NPV) ▪ (<i>AgrotisIpsilon</i> – Multiple Nuclear Polyhedrosis Virus) ▪ (<i>HeliothisZea</i> – NPV) 	NPVs are a virus of caterpillars that occur in Australia used for insect control in IPM. (Senthil-Nathan and Sengottayan, 2015)
Granulovirus (GVs) <ul style="list-style-type: none"> ▪ Madex – TM (Genetically Engineered Granulo Viruses) 	Rod- Shaped double stranded DNA viruses, infect on wide range of Lepidopteran and Hymenopteran insects. (Senthil-Nathan and Sengottayan, 2015)

▪ **Nematodes**

One of the new hot products in Biopesticides are nematodes. In 1990’s, many entopathogenic nematodes were discovered as biocontrol agents.

Mode of Action

Insect Parasitic nematodes may infect soil dwelling stages of insects and kill them within 48h through expulsion of pathogenic bacteria. After host dies, the infectious stages of nematodes become adults and a modern generation of infective juveniles develops. They commonly lead to their parasitic cycle through 3rd stage juveniles. These non-infective forms infest the host insect body through anus, mouth and spiracles. Once infested onto the host, they remain always in the host and go to haemocoel and release their symbiotic bacteria into ventriculus of insect. Then bacteria cause septicaemia and within 24 – 48 h insects die. A recent study on nematode Biopesticides reveals that – these are most effective against Pyralidae, Curculionidae, etc.

Examples of Pathogenic Nematodes

1. *Steinernema sp.*
2. *Heterorhabditis sp.*

Table 8

Examples of Pathogenic Nematodes	Brief Descriptions
<i>Steinernema sp.</i>	The <i>Steinernema sp.</i> is considered as a generalist parasite and has been effectively used to control a variety of insects including: flies, flea, ants, termites, webworms, cutworms, armyworms, girdlers, some weevils, and wood-borers. (Senthil-Nathan and Sengottayan, 2015)
<i>Heterorhabditis sp.</i>	<i>Heterorhabditis sp.</i> is obligate parasite of insects, used as biological control agents for the control of insect pests. (Senthil-Nathan and Sengottayan, 2015)

▪ **Protozoa**

Protozoa diseases are ubiquitous in nature and constitute essential regulatory role in insect populations.

Mode of Action

Slow acting Protozoa mainly acts on the insects’ health. They cause chronic infections. Biological activities are very complex in nature.

1. They grow only on living hosts or some species prefer to live in the intermediate host.

2. Microsporidia species are among the most commonly observed and their main benefits are persistence and recycling in host populations and their debilitating effect on reproduction and overall fitness of target insects.
3. Protozoans produce spores which are infectious to several insect pests.
4. These go to midgut and after germination invade the host target cell and sporulation occurs.
5. As a result of this epizootic infection, insect dies.
6. It is target specific and safe.

Examples of Pathogenic Protozoa

1. *Nosema locustae*
2. *Nosema bombycis*

Table 9

Examples of Pathogenic Protozoa	Brief Descriptions
<i>Nosema locustae</i>	<i>Nosema locustae</i> is an important protozoan genus used in agriculture for destroying the attack of Locust and Grasshopper. (Senthil-Nathan and Sengottayan, 2015) (Henry and Oma, 1981)
<i>Nosemabombycis</i>	<i>Nosema bombycis</i> is an important protozoon used in the agriculture for destroying the attack of Silkworm pebrine disease. (Senthil-Nathan and Sengottayan, 2015) (Becnel and Andreadis, 1999)

▪ **Others (Spirochaetes)**

Some Spirochaetes cause serious harmful effects on insects. They block their respiration, nervous systems and so, insects die. Examples of their use in agricultural sector are few only.

Examples of Pathogenic Spirochaetes

1. *Leptospira sp.*

Table 10

Examples of Pathogenic Spirochaetes	Brief Descriptions
<i>Leptospira sp.</i>	It is one type of Spirochaete that causes disorder of nervous system in insects. (Senthil-Nathan and Sengottayan, 2015)

Advantages & Disadvantages of Biopesticides

▪ **Advantages**

1. **Host Specificity:** Biopesticides normally do not exhibit harmful effects on beneficial insects. Always they are target specific.
2. **Ability in Multiplication:** Biopesticides easily are multiplied in the target cells, mainly in midgut epithelium cells of insects.
3. **Less Toxicity:** Biopesticides are totally safe, non-toxic or less toxic, so, no harmful effect occurs.
4. **No Evidence of Insect Resistance:** Biopesticides are very effective, have no evidences of pest resistance against it.

5. **No Cross-Resistance Problem:** Biopesticides have no fear of cross resistance problems.
 6. **Conventional Technique:** It is very well efficient and are used in IPM authorities.
 7. **Long Persisting Effect:** Once it is used, its effect persists for longer time. So, insects are deterred from agricultural crop fields.
 8. **No Pollution:** It is totally eco-friendly as these are natural products and cause no pollution.
 9. **No Fear of Biomagnification or Bioaccumulations:** Biopesticides are biodegradable products. So, have no fear of Biomagnification and Bioaccumulations.
- **Disadvantages**
1. **High Selectivity or Host Specific:** Biopesticides generally are highly selective and host specific in nature. These products only kill a particular pest species. So, different Biopesticides need to be applied to control different pest species. This is somehow problematic.
 2. **Requirement of Additional control Measures:** Biopesticides requires additional control measures. This control measure sometimes becomes costly.
 3. **Delayed Effect:** Sometimes Biopesticides produce delayed effect so, pest easily enjoy and damage the crops.
4. **Storage Problem:** Biopesticides rapidly spoiled in environment due to short shelf-life. So, it cannot be stored for a longer time.
 5. **Difficulties in Culturing in Large Quantities:** It has difficulties in production of large quantities.
 6. **Short Residual effectiveness:** It has short residual effectiveness, needs repeated applications.

Biorationals

What are Biorationals

The term Biorationals is very confusing. Precise usage of this term is difficult to describe.

Plimer (1985) tied the term Biorationals to the process by which the control agent is designed and synthesized. He explained that – “the exploitation of knowledge about plant or animal biochemistry will be in order to synthesize a new molecule designed to act at a particular site or to block a key step in a biochemical process.”

Diver and Hinnmarr (2008) described that – “Biorationals are products produced by biological organisms that are narrower in spectrum and less toxic.”

Finally, Carl Djerassi (1974) Produced examples and best definitions of Biorationals as – “Any type of insecticide active against pest populations, but relatively innocuous to non-target organisms and therefore, non-disruptive to biological control”

Common Examples of Biorationals

Common examples are Pheromones, Insect hormones and Hormone antagonist.

Table 11

Examples of Important Biorationals	Brief Mode of Action and Descriptions	Successful Usages
Oils ▪ (Paraffinic Oils) ▪ (Kerosene Oils)	These are repellent. Highly systemic, as a result, Insect can deter from the place. It is a Systemic Poison. (Schuster and Stansly, 2021)	These can successfully evade Whiteflies nymphs (<i>Encarsia pergandiella</i>) from crop.
Soap	Soap is the highly toxic when in wet condition. Moderately Toxic on Beneficial Insects. (Schuster and Stansly, 2021)	It is well known toxic against Whiteflies in agriculture
Cow Dung	Cow dung is sometimes used as a component in natural insect repellents and compost teas, which can help in pest and disease control. (Raj <i>et al.</i> , 2014)	It is well known toxic against adults of aphids in caterpillars, beetles, and leafhoppers.
Cow Urine	Cow urine has been traditionally used in organic farming as a foliar spray to deter pests and diseases. Some studies suggest that cow urine may have antifeedant and growth inhibitory effects on certain insect pests, reducing their populations and damage to crops. (Raj <i>et al.</i> , 2014)	It is well known toxic against adults of aphids in caterpillars, beetles, and leafhoppers.
Tebufofenozide, Methoxyfenozide and Novaluron	These are the Insect Growth Regulators, affect direct development of the larval stages, have minimal effect on natural enemies. (Schuster and Stansly, 2021)	It is well known toxic against larval stages of the Southern Beetle and other worms and also effective for tomato pests.
Pymetrozine, Pyriproxyfen and Buprofezin	These are active against pest, highly systematic. These inhibit the final moulting of the insects. (Schuster and Stansly, 2021)	It is well known toxic against adults of whiteflies, aphids.
Neem Materials	It is reportedly well-known toxic. It is non-toxic to non-target organisms like predators (Schuster and Stansly, 2021)	It is well known toxic against whiteflies in agriculture
Bt Toxins	It is one type of Gram – positive bacteria. It is temperature, UV-Light resistant. It has an important role in preventing the plant diseases and insect pests. (Senthil-Nathan and Sengottayan, 2015)	It is well known toxins for many types of insects on brinjal, tomato.
Pyridalyl	Pyridalyl is a relatively new insecticide. Pyridalyl works by disrupting the nervous system of insects, leading to paralysis and eventually death. (Senthil-Nathan, Sengottayan, 2015)	It is well known toxic against thrips.
Spinosad	Spinosad is a natural substance derived from the fermentation of a soil bacterium called <i>Saccharopolyspora spinosa</i> . It is commonly used as an insecticide in agriculture and gardening. (Schuster and	Spinosad is effective against a wide range of pests, including caterpillars, beetles, thrips, and leaf miners.

	Stansly, 2021)	
Nicotinoids	Highly Systematic against adults, nymphs, larvae of many pests. This is a product from Tobacco Plants., (Schuster and Stansly, 2021)	It is effective against whiteflies and aphids.

Advantages & Disadvantages of Biorationals

▪ **Advantages**

1. Less toxic
2. Target specific
3. Biodegradable compounds
4. Easily available
5. Low Cost

▪ **Disadvantages**

1. Delayed effect
2. Storage problems
3. Not well efficient for potential pests

Hormonal Controls

What is Hormonal Controls

Hormones are the biological products that are natural or synthetic in origin, have ability to control behavioural changes in organisms. These are the biochemical products. Various types of Hormones are used for insect control purposes.

Common Examples of Hormonal controls

Some basic examples are:

Table 12

Types of Hormonal controls	Examples of Important Hormonal control agents
IGR or Insect Growth Regulator It is the hormone that check the moulting and pupation of insects as these hormones are target specific. So, affects only on particular pest. (Schuster and Stansly, 2021)	Tebufenozide, Methoxyfenozide and Novaluron effect on many pests like Whiteflies and Aphids etc. GABA effects on insect nervous system. It acts as an inhibitory neurotransmitter. Pyriproxyfen and Buprofezin act on Aphids. Excessive Ecdysteroid effects on moulting of insect populations.
CSI or Chitin Synthesis Inhibitor This is a new class of hormonal control agents. It blocks the chitin synthesis in insects. (Schuster and Stansly, 2021)	Benzoyl Phenyl Urea (BPU) analogue, this mainly acts as Stomach poison can kill insects at the time of moulting. Diflubenzuron b used for controlling insect pests. It acts as a CSI, cannot be synthesized.
JH or Juvenile Hormone Juvenile hormone is the important hormone produced from corpora allata of insect brain. It retains the juvenile stage of insects. This hormone ceases pupation of larve. (Schuster and Stansly, 2021) (Senthil-Nathan and Sengottayan, 2015). (Samada and Tambunan, 2020).	Fenoxycarb, Methoprene are the JH Analogs. When insect pupation does not occur, then their larval tissue apoptosis occurs and then easily dies in a particular time. It is well efficient and safest technique that cannot cause any harmful effects on beneficial insects.

Advantages & Disadvantages of Biorationals

▪ **Advantages**

1. **Species specific:** Hormones are always species specific.
2. **Non-Toxic:** Hormones like IGR, CSI chemicals are totally non-toxic in nature.
3. **Survival of Beneficial Insects:** Beneficial insects can easily survive without any fear of severe cross effect on them.
4. **Rapid working:** It is volatile compounds, so, mixes in air rapidly and acts also fast.

▪ **Disadvantages**

1. **Narrow spectrum:** It having narrow spectrum properties and hence less effective.
2. **Volatility problem:** Sometimes excessive volatility cannot give required effect on agricultural pests.
3. **Costly:** The production of those hormones is much costlier.
4. **Highly selectivity:** Due to being highly selective to host species, it is worst choice for agricultural use.

Difference between Chemical Pesticides and Biopesticides

1. Chemical pesticides can kill the non-targeted or beneficial insects but Biopesticides cannot. Like –

- DDT, BHC can kill beneficial like wasp, trachinids flies but Biopesticides do not.
2. Chemical Pesticides are normally non-biodegradable, so, it leaves residues in food. So, have a problem of Biomagnification but Biopesticides cannot leave residues. DDT is an Organochlorine compound remains residues.
3. Have problems of insect resistance properties, but Biopesticides does not face those types of problems – Carbamates, Baygon are chemicals that develop easy residue on pests.
4. Chemical pesticides are costly but Biopesticides are cheaper.

Effects of Biopesticides on Pollinators, Beneficial Predators and Parasitoids

Biopesticides, often are considered safer alternatives to conventional chemical pesticides, can still have various effects on pollinators, beneficial predators, and parasitoids. Here are some potential effects: -

1. Effects on Pollinators

Positive Effects

Microbial agents like Bacillus thuringiensis (BT) and plant extracts such as neem oil minimally impact pollinators when used properly. Being specific to pests and low in toxicity to non-target organisms, Insect growth regulators (IGRs) and mating disruptors target pests without affecting pollinators.

Negative Effects

Botanical extracts like pyrethrins or rotenone can be toxic to bees, butterflies, and other pollinators if injudiciously used during flowering periods. Residues on crops or in the environment can harm pollinators through contact with contaminated surfaces or water.

2. Effects on Beneficial Predators

Positive Effects

Narrow-spectrum Biopesticides spare beneficial predators by targeting specific pests. Microbial Biopesticides like Bt are selective, affecting pest larvae but not predators like ladybugs and lacewings.

Negative Effects

Broad-spectrum Biopesticides can harm beneficial predators if overused or if non-selective. Residual toxicity can affect predators through contact with treated plants or prey.

3. Effects on Beneficial Parasitoids

Positive Effects

Specific Biopesticides benefit parasitoids by reducing host pest populations without harming non-target organisms. Biopesticides based on fungi or viruses can selectively affect pests while sparing parasitoids.

Negative Effects

Non-specific or broad-spectrum Biopesticides can harm parasitoids directly or deplete host populations. Sub-lethal effects on pests can also affect success of parasitoids by reducing host quality or availability.

Future Scope or Status of Biopesticides and Biorationals

Farmers need safer pesticides for crop protection, making Biopesticides as preferable option over chemical pesticides. Despite challenges in formulation and development, further research and product development are essential for commercializing Biopesticides. Public funding and commercial investment are crucial for establishing eco-friendly Biopesticides production, particularly in developing countries where funding is a major hurdle. Integrated Pest Management (IPM) advocates minimal use of conventional chemical pesticides to prevent pest resistance. Future prospects include BT toxins from *Bacillus thuringiensis* bacteria; genetically engineering plants with BT toxin genes could confer pest resistance. Crystal proteins in powder form and Baculoviruses are also effective for pest control, with reports indicating success against Velvet bean caterpillars in soybeans, offering a feasible and cost-effective solution. Using genetically unmodified Baculoviruses as biological pesticides is viable, and *in-vitro* culture development and formulation changes suggest potential improvements. Current studies show high efficacy of various botanicals and Neem Biopesticides. Biorationals, including synthetic hormones, also show promise in agriculture. Commercialization is crucial for all products. Future considerations favour Biolarvicides due to their activity, low costs, and effectiveness in anopheline larvae feeding zones, highlighting the need for extensive research and application development in Biopesticides and Biorationals. Future consideration should focus on production of biolarvicides against anopheline larvae.

Conclusion

On the lessons of this review it may be concluded that – Biopesticides play important role in IPM by reducing the use of synthetic chemical pesticides that are harmful to human and environmental health. Some biopesticides which dominate global market including BT, Neem, Baculoviruses, and Trichoderma. These products do not cause environmental damage and improve crop yields. Biopesticides and Biorationals are very cheaper and better option against chemical pesticides. So, focus should be made on research regarding formulation and production of these products. Biopesticides and Biorationals are better choice for pest management, especially to maintain an improved balance between cost and efficiency. This will focus future research programme in management of agriculture and medical pests.

Acknowledgement

The senior author is thankful to the Principal, Barasat Government College and Dr. Sumana Saha, Head of the PG Department of Zoology, Barasat Government College for providing infrastructure facilities and encouragements. Both the authors are thankful to Secretary, Ramakrishna Mission Ashrama, Narendrapur for providing laboratory facilities.

References

1. Alizadeh I. Study the repellent of oregano essential oil (*Origanum vulgare*) in comparison with DEET (N, N-Diethyl-Meta-Toluamide) as a synthetic repellent for personal protection against bed bug, *Cimex lectularius* in laboratory. Tehran University of Medical Sciences, 2016.
2. Appiya Chinnamma, Dr. C. & Department of Sericulture, Govt. Degree College, Kadiri, Anantapur (Dist), Andhra Pradesh-515591, India. Influence of petroleum ether leaf extract of *Vitex negundo* on the oviposition deterrence of adult *Uzifly* (*Exorista bombycis*). International Journal of Innovative Science and Research Technology, 2017;2(5):31-32.
3. Baliota GV, Athanassiou CG. Use of paraffin oils in agriculture and beyond: back to the future. Environmental Science and Pollution Research International, 2022;30(2):2392-2405.
4. Damalas CA. Potential Uses of Turmeric (*Curcuma longa*) Products as Alternative Means of Pest Management in Crop Production. Plant Omics, 2011;4(3):136-141.
5. Department of Zoology, Faculty of Science, DayalBagh Educational Institute, DayalBagh, Agra (U.P.)-282005, India & Division of Animal Health, Central Institute for Research on Goats, Makhdoom, P.O. Farah, Mathura (U.P.)-281122, India. Evaluation of mosquito repellent efficacy of *Ocimum sanctum* plant extract. Journal of Herbal Medicine and Toxicology, 2009;3(1):87-90.
6. Elanchezhyan K, Vinothkumar B. Neem: an Eco-Friendly botanical insecticide in pest management. The Journal of Insect Science, 2015, 207-217.
7. Felix Amuji C, Echezona B, Dialoke S. Extraction fractions of ginger (*Zingiber officinale* Roscoe) and residue in the control of field and storage pest. Journal of Agricultural Technology, 2012;8(6):1686-9141.
8. Haro González JN, Castillo Herrera GA, Martínez Velázquez M, Espinosa Andrews H. Clove Essential Oil (*Syzygium aromaticum* L. Myrtaceae): Extraction,

- Chemical Composition, Food Applications, and Essential Bioactivity for Human Health. *Molecules*,2021:26(21):6387.
9. Kabir AKMA, Kabir H, Md. J, Gulshan Z, Dhakal HR, Amin MR, Rahman AM, Faruk-ul-Alam S. Application of cow urine as bio-fertilizer and bio-pesticide in boro rice production of Bangladesh. *Research in Agriculture Livestock and Fisheries*, 2022, 165-169.
 10. Kesavan P, Swaminathan M. Strategies and models for agricultural sustainability in developing Asian countries. *Philosophical Transactions of the Royal Society. Biological Sciences*,2007:363(1492):877-891.
 11. Kulma M, Bubová T, Kopecký O, Rettich F. Lavender, eucalyptus, and orange essential oils as repellents against *Ixodes ricinus* females. *Scientia Agriculturae Bohemica*,2017:48(2):76-81.
 12. Kumar V, Chandrashekar K, Prakash Sidhu O. Efficacy of karanjin and different extracts of *Pongamia pinnata* against selected insect pests. *Journal of Entomological Research*,2006:30(2):103-108.
 13. Mascarin GM, Brazilian Agricultural Research Corporation (EMBRAPA), Jaronski T, MYCOsystems Consulting LLC. The production and uses of *Beauveria bassiana* as a microbial insecticide. *World Journal of Microbiology and Biotechnology*, 2016.
 14. Munyore M, Rioba NB. Evaluation of garlic (*Allium sativum*) and onion (*Allium cepa*) extracts for the management of fall armyworm (*Spodoptera frugiperda*) on baby corn (*Zea mays* L) under greenhouse conditions. *Science Heritage Journal*,2020:4(2):64-69.
 15. Nirgundi (*Vitex negundo*) – Nature’s Gift to Mankind. *Asian Agri-History*, 2015, 5-32.
 16. Rinaldi S, Casorri L, Masciarelli E, Ficociello B, Visconti U, Papetti P, Neri U, Beni C. Prospects of using garlic extracts for pest control in sustainable agriculture. *Fresenius Environmental Bulletin*,2019:28(2):535-540.
 17. Routray S, Kabi M, Debnath D, Palei S. Potential of *Lantana camara* L. extracts as biopesticide against insect pests. *Journal of Entomological Research*,2021:45(3):461-469.
 18. Samada LH, Tambunan USF. Biopesticides as promising alternatives to chemical pesticides: A review of their current and future status. *Online Journal of Biological Sciences*,2020:20(2):66-76.
 19. Sathe TVSPV, Sathe NT, Ghodake D, Sathe AS. Sucking insect pests and medicinal value of *Tulsi Ocimum sanctum* L. (Lamiaceae). *Indian Journal of Applied Research*,2011:4(3):31-33.
 20. Schuster D, Stansly P. *Biorational insecticides*, 2021.
 21. Senthil Nathan S. A review of Biopesticides and their mode of action against insect pests. *Springer eBooks*, 2014, 49-63.
 22. Shrivastava A, Amity University Raipur. A review on peppermint oil. *Asian Journal of Pharmaceutical and Clinical Research*, 2009, 2(2).
 23. Singh Y, Mishra P, Kannoja P. Morphology, Phytochemistry and Pharmacological Activity of *Vitex negundo*: An Overview. *Journal of Drug Delivery and Therapeutics*,2020:10(3-s):280-285.
 24. Subramaniam MSR, Babu A, Deka B. *Lecanicillium lecanii* (Zimmermann) Zare & Gams, as an efficient biocontrol agent of tea thrips, *Scirtothrips bispinosus* Bagnall (Thysanoptera: Thripidae). *Egyptian Journal of Biological Pest Control*, 2021, 31(1).
 25. Ullah MI, Majeed S, Arshad M, Ali S, Mehmood N, Altaf N, Abdullah A, Luqman M, Farooq U, Afzal M. Insecticidal effects of *Parthenium hysterophorus* and *Moringa oleifera* leaf extracts on digestibility indices and survival of *Spodoptera litura* (Lepidoptera: Noctuidae). *Asian Journal of Agriculture and Biology*, 2022.
 26. Zulkefli N, Ghani WWAK, Ali S, Asib N, Chowmasundaram Y. Development of bio-pesticides from bio-oil of oil palm biomass waste (palm kernel shell) against *Metisa plana* Walker bagworm (Lepidoptera: Psychidae). *Food Research*,2021:5(S1):137-143.