# Biopesticide: An Approach Towards Pest Management for Maintaining a Healthy Lifestyle

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**ABSTRACT**

The review comprises the advantages of biopesticides, classification, mode of action and formulation, global and Indian perspectives towards biopesticides. Crop protection by pesticides is the traditional way to control the multiplication of pests. Despite the harmful influences of chemical pesticides on the yield and quality of crops for the management of different kinds of pests on plants, they are still used globally due to the less time of lethality of pests with the association of more harmful implications. To minimize the drawback of synthetic pesticides, the alternative has been developed by researchers that arenaturally derived from a microorganism (bacteria, viruses, fungi), herbal extracts from plants, pest-resistant crop development by genetic modification, and Semiochemicals (Insect pheromones). The alternative is coined "Biopesticide"due to originating from natural sources for the control or mortal effect on pests. Biopesticide has numerous advantages over synthetic pesticides: fewer side effects, minimum chances of resistance development, less environmental hazard, cost-effectiveness, biodegradability, and target specificity.

**Key Words:** *Crop protection, Biopesticide, Semiochemicals, Synthetic pesticide, Biochemical*

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## INTRODUCTION

Plant pathogens like bacteria, viruses, fungi, nematodes, insects, and weeds affect the quality and yield of crops. These pathogens are named pests, and the products used to prevent pests are called pesticides. The pest management techniques are based on preventive or lethal for pests, using synthetic or natural pesticides. Still, synthetic pesticides pose numerous environmental hazards to plants and affect soil quality [1]. Therefore, biopesticide use for pest management is a global demand to improve crop yield and minimize the hazardous effects of biopesticide [2]. Biopesticides can occur from microorganisms (Bacteria, fungi, viruses, and entomopathogenic nematodes linked by some symbiotic bacteria), phytochemical-derived, pest-resistant crop production by genetically modified organisms, and some animal-derived products like (insect pheromones aka semiochemicals, hormones, and insect-specific toxins) [3].

Biopesticides could be a safer tool in the Integrated Pest Management (IPM) Technique, which enforces the combined tactics of crop protection rather than individual pest control methods. So, producing viable biopesticide should be cost-effective, have good enduring capacity, be biodegradable, require minimum quantity for efficacy, have tenacious loading capability, and be easy to handle, blend, and spread [4].

*Why biopesticide*

The agricultural production pesticides became a vital tool to improve crop yield and plant protection. The Pesticides include a wide variety of herbicides, insecticides, fungicides, rodenticides, and nematicides [5]. Natural and synthetic pesticides are available in the market to control pests, weeds, and plant diseases. Consequently, around 45% of annual food production is lost due to pest infestation and poor pest management. There is a wide range of synthetic pesticides for crop management like dichloro-diphenyl-trichloro-ethane (DDT), hexachlorobenzene, aldrin, heptachlor, endrin, mirex, dieldrin and chlordane to impose a calamitous effect on the health of human, grazing animals and environment [6]. The persistent use and ubiquitous nature of synthetic

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pesticides-imposed chaos on humanity due to the bioaccumulation properties and higher toxicity by obstructing the normal functioning of living organisms' endocrine and reproductive systems [6].
Pesticide usage is rapidly increasing in developing and developed countries to control the growth rate of pests, especially in Southeast Asia. According to a WHO report, developing countries use 20% of pesticides, which increases daily. The manufacturing of pesticides started in 1952 in India. In 1958, pesticide production was more than 5,000 metric tons, but it drastically increased to 85000 metric tons in the1990s. India started the production of DDT and benzene hexachloride in 1952, and 2 approx. Among most insecticides, one hundred forty-five pesticides [7] were registered till the mid-1990s, placing India in the twelth position in the world [8]. Utilization of synthetic pesticides causes'harmful effects such as pesticide residual on plants, soil, air, and water, which produces a threatening effect on human health (Bronchial trouble, Carcinogenic, Neurotoxic, causes amnesia in human beings), causes reappearance of pests in multiple uses, secondary pest eruption and pest resistance and agro-ecosystem imbalance [9]. The plant secondary metabolite reveals a broad range of complex interactionsdue to the presence of essential oil constituents, alkaloids, vegetable oils, fatty acids and soaps, leaf waxes and exudated, cleorane diterpenes, Nicotene, Rotenone, pyrethrums, sabadilla, isobutyl amides, Limonoids, saponins and sapogenins, Naphthaquinones, Rocaglamides, Polyol esters, Acetogenins, Light activated photo toxins and Miscellaneous phytochemical pesticides [5]. In ancient times, Plants and plant-derived phyto metabolites were used to protect crops from unwanted pests and insects. Neem oil extracted from seeds of *Azadiracta indica* and some essential oils from citrus and other plant species are used for the protection of insects in post-harvest care [10]. The biopesticides derived from Phytoconstituents are effective on organic food products and post-harvest protection techniques. The herbal biopesticide impeded the target-specific pest broadly [5].

*Biopesticide categorization*
Biopesticides may be generally categorized into three foremost groups as discussed in detailed form in **Figure 1**, namely- 1) Microbial biopesticide, 2) Biochemical Pesticide, 3) Plant incorporated protectant [3].

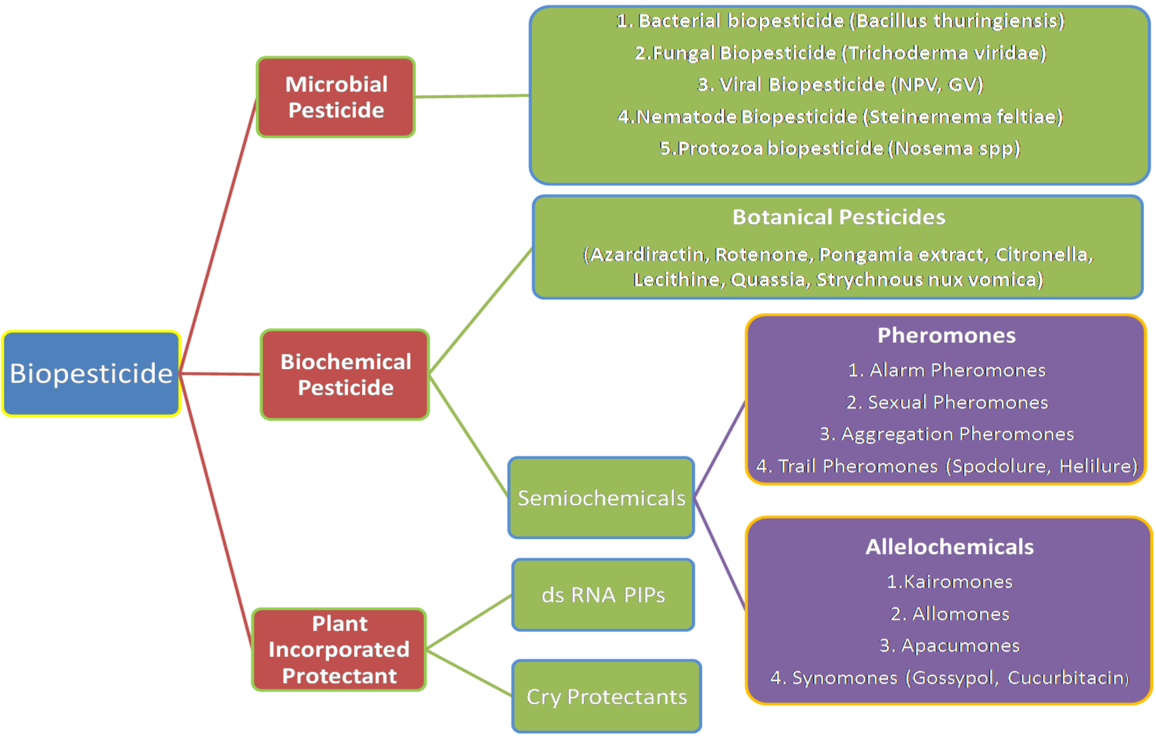


**Figure 1.** Categorization of Biopesticides [11]

*Microbial biopesticides*
Living microorganisms such as bacteria, fungi, viruses, or baculoviruses, protozoans are used as microbial biopesticides to kill the pathogens on the crop. Bacterium *Bacillus thuringinesis* orbtis is used against the insects found on vegetable crops such as potatoes and cabbage. Some other microbial biopesticide formulations are bioherbicide (Phytophthora species), bio-fungicide (Trichoderma species), and bioinsecticides (*Agrobacterium radiobacter*) [12, 13]. Cydiapomonella granulo virus treats codling moths in apples, while ascomycetes-based Beauveria bassiana or metarhizium

anisopliae is used to treat spittlebugs in sugarcane. Crown gall disease can be controlled by Agrobacterium radiobacter [4, 14].

*Mechanism of action*

Microorganisms used as pesticides produce some endotoxins to prevent the growth of other pathogenic organisms such as Bt, which produce some toxic metabolite during spore formation and cause lysis of gut cells when administered by insects. Some chitinolytic enzymes like glucanase, cellulose, and proteases are also released by *Trichoderma* that prevent the growth of fungi by degradation of the cell wall and multiply its spores in disease-causing fungi. A virus or Bacteriophage enters into the cell wall of disease-causing bacteria. Similarly, baculoviruses are defined by Occluded Budded Virus that is morphologically divided into two classes: Nucleo polyhedron virus (NPVs) and Granulovirus (GVs) [14].

*Biochemical biopesticides*

Biochemical pesticides are plant and animal-derived pesticides that function by non-toxic mechanisms. Traditionally, herbal phyto metabolites are used to protect crops from pathogenic microorganisms or pests and post-harvest care from insects. Another typeof biochemical pesticide are plant growth regulators or substances that attract or repel pests like semiochemicals (insect pheromones) [4].

*Plant secondary metabolites (Botanical biopesticides)*

The plant secondary metabolites called botanicals are used as insecticidal, anti-feedant, and repellent due to the presence of terpenoids, tannins, alkaloids, coumarins, flavonoids, quinones, saponins, phenols, and sterols. Some examples of repellents (citronella), fungicides (laminarine, fennel oil, lecithin), insecticides (pyrethrum, rape seed oil, neem oil, quassia, nicotine), herbicides (pine oil), sprouting inhibitors (Caraway seed oil) [14] and antifeedants (Vitex nigundo, Strychinous nux vomica, Murraya koeingii) [15].

*Mode of action:* Botanicals isolated from herbal plants caused neurotoxicity in pathogenic insects [14].

*Categorization of botanical insecticides:* conventionally classified the plant components into 6 groups, namely repellents, feeding deterrents/antifeedants, toxicants, growth retardants, chemosterilants, and attractants [16].

1. *Repellent:* The repellents are plant-derived enviable chemicals as they offer protection with the least impact on the ecosystem, as they drive away the insect pest from the treated materials by stimulating olfactory or other receptors. For example, the essential oil of *Artemisia annua* was found to berepellent against *Triboliumcastaneum* and *Callosobruchus maculates* [17].
2. *Feeding deterrents/antifeedants:* chemicals that inhibit feeding or disrupt insect feeding by rendering the treated materials unattractive or unpalatable [18, 19]. Essential oil constituents such as thymol, citronellal, and α-terpineol are effective as feeding deterrents against tobacco cutworm, *Spodoptera litura* [20].
3. *Toxicants:* Numerous plant species exhibit toxicant effects of different species of stored-products insects. The literature survey revealed that *Anabasis hispanica*, *Seneciolopezii*, *Bellardia trixago*, and *Asphodelus fistulosus* showed promising toxicity against stored grains insect *Tribolium castaneum* [21]. The methyl allyl disulfide and diallyl trisulfide are two major components of the essential oil of garlic, potent toxicants and fumigants against *Sitophilus zeamais* and *Tribolium castaneum* [22].
4. *Grain protectant:* The plant parts such as leaf, bark, seed powder, or oil extracts are used as grain protectant, which reduces the oviposition rate and suppresses adult emergence of stored product insects as well as reduces seed damage rates [23, 24]. For example, the neem oil and kernel powder are used as grain protectants against *Sitophilus oryzae*, *Tribolium cataneum*, *Rhyzopertha dominica*, and *Callosobruchus chinensis* at the rate of 1 to 2% kernel powder or oil [25]. Some natural chemical constituents and allelochemicals, including azadirachtin, nicotine, and rotenone, are traditionally claimed as grain protectants [26]. While some powdered plant materials like *Rauvolfia serpentina*, *Acorus calamus*, and *Mesua ferrea* are used as grain protectants against *Rhyzopertha dominica* [27].
5. *Chemosterilants/ reproduction inhibitors:* The literature survey revealed that the plant parts such as oil, extracts, and powder mixed with grain-reduced insect oviposition, egg hatchability, postembryonic development, and progeny production [28].
6. *Insect growth and development inhibitors*: Some plant extracts showed harmful effects on the growth and development of insects and reduced larval pupal and adult weight significantly, lengthened the larval and pupal periods, and reduced pupal recovery and adult eclosion [29].

*Semiochemicals (Sex hormones or pheromones)*

Insects released some synthetic analogs or chemicals that have information for other insects for either mating or repellency; this behavioral character induced some responses like sex hormones, aggregation pheromones, and alarm hormones. Currently, these semiochemicals are of significant interest to researchers due to their property to identify and mate with specific pest species to protect the crop and used as pesticides [30]. The pheromones are named based on the presence of functional groups, aliphatic chain length, geometric configuration, and unsaturated position (aldehyde, alcohol, acetate, epoxide, and hydrocarbons). According to Pherolist, 185000 moth species are identified, among which 377 pheromones have been detected in 1572 species of 619 genera [31]. Lepidopterans are secreated by butterflies and moths, a straight chain utilized as an insecticide [3].

*Plant incorporated protectant*

These are biotechnologically transformed or combined products of altered gene expression with improved insecticidal activity along with some other benefit, for example, the combination of Bacillis thuringiensis with binary toxins of Bacillus sphaericus expressed insecticidal as well as mosquitocidal vectors for malaria, filariasis, and dengue fever [32]. Another example of feeding activity enhancement of infected Baculovirus larvae is deleting the ecdysteroid UDP glycosyltransferase (egt) gene by genetic engineering [14]. These type of genetically modified plants produces biodegradable proteins and exhibits a beneficial effect on the crop with no hazardous effect on human, animal, and the environment [3].

*Production of biopesticide*

Generally, biopesticides are viable microorganisms that require specific formulation and storage facilities. During the formulation of biopesticide, the researchers face many considerable problems, such as loss of viability at the time of application, the compatibility of microbial strain with different carrier and solvent systems, stability during storage and handling, and, most importantly through fundamental knowledge of active bioagent (Microorganism, plant metabolite, semiochemical, and GM plants) and target pathogenic insect. The handling problems like droplet size selection, better spray retention, and deposition of bioagent on the leaf surface are most important during application for the efficacy of biopesticide. The biopesticide can be formulated **(Table 1)**. Formulation category of biopesticides) as dry and liquid formulations [2].

**Table 1.** Formulation category of biopesticides [2]

| S.No. | Dry formulation | Liquid formulation |
|---|---|---|
| 1 | Dust protectants | Emulsion suspension concentrates |
| 2 | Seed Dressing powders | Oil dispersions |
| 3 | Granules | Suspo emulsions |
| 4 | Microgranules | Capsule suspensions |
| 5 | Water dispersible granules | Ultra-low volume formulations |
| 6 | Wettable powders | |

*Production and consumption of biopesticides in India*

India is a diversified country and is progressing daily in utilizing advanced technology along with its traditional secrets of preservation and usage of biopesticides. According to recent reports, India has 410 production units among all; 130 are private, and the government runs 280 units. Although there are 26 units from the Central Integrated Pest Management Center, 31 units from ICAR/SAU (Council of Indian Agricultural Research Institutes/State Agricultural Universities), 22 units are funded supported by the Department of Biotechnology and various public sector entities including government-owned biocontrol laboratories [33]. According to the General Department of Plant Protection, Quarantine and Preservation, both under the Central Integrated Pest Management Center, these are the main government organizations involved in biopesticide production [34].

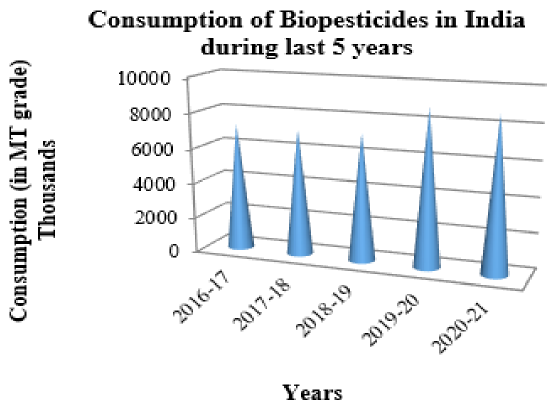


**Figure 2.** Consumption of Biopesticides in India during the last fiveyears [35, 36]

The above graph **(Figure 2)** represents the consumption of biopesticides in India; as of now, the consumption is 9%, but by 2050, it is estimated to increase up to 50% of total pesticide consumption. Also, the expected growth rate is 2.5% [35, 36]. The real trend expresses lower utilization of biopesticides in India. The statistics **(Figure 3)** [37] showed that some states like Maharashtra, West Bengal, and Karnataka consumed the maximum amount of biopesticides at 5549, 4416, and 3478 MT each, respectively. In contrast, Goa and Himachal Pradesh consumed the least amount at 38 and 36 MT each, respectively. Hence, the overall consumption of biopesticides has sharply enhanced in Rajasthan and Andhra Pradesh and suddenly decreased in Orissa. Consumption of biopesticide was formerly increased but later in 2020-2022 decreased in Maharashtra and Kerala. This sharp fall needs awareness camps and education on the benefits of biopesticides. These data also explain why biocontrol initiatives in the northern states of the country have had less impact than initiatives in southern regions [34, 38]. The use of biopesticides increased spectacularly from 123 MT (metric tons) in 1994-1995 to 8110 MT in 2011-12 [39]. However, the use of biopesticides increased by 40% in India between 2014-15.and 2018-19, based on PPQS statistics [37]. As time passed, the usage increased by 8847 and 8645 MT in 2019-2020 and 2020-21, respectively **(Figure 3)**. Meanwhile, the consumption of chemical pesticides **(Figure 4)** comparatively decreased from 56114 MT to 43584 MT [40].

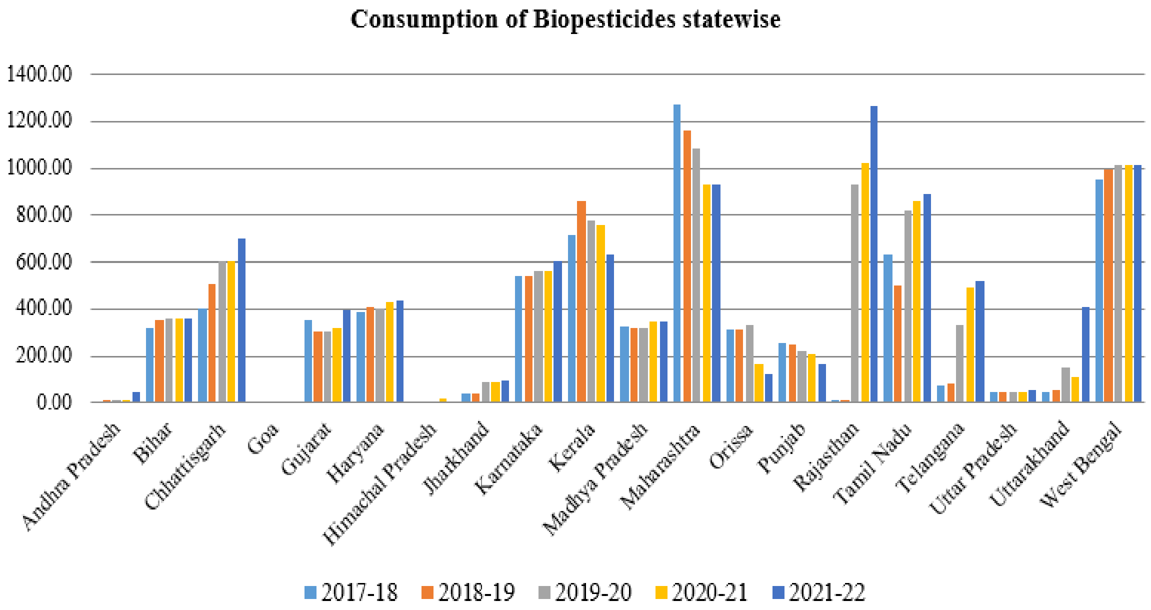


**Figure 3.** Consumption of biopesticide state-wise [40].

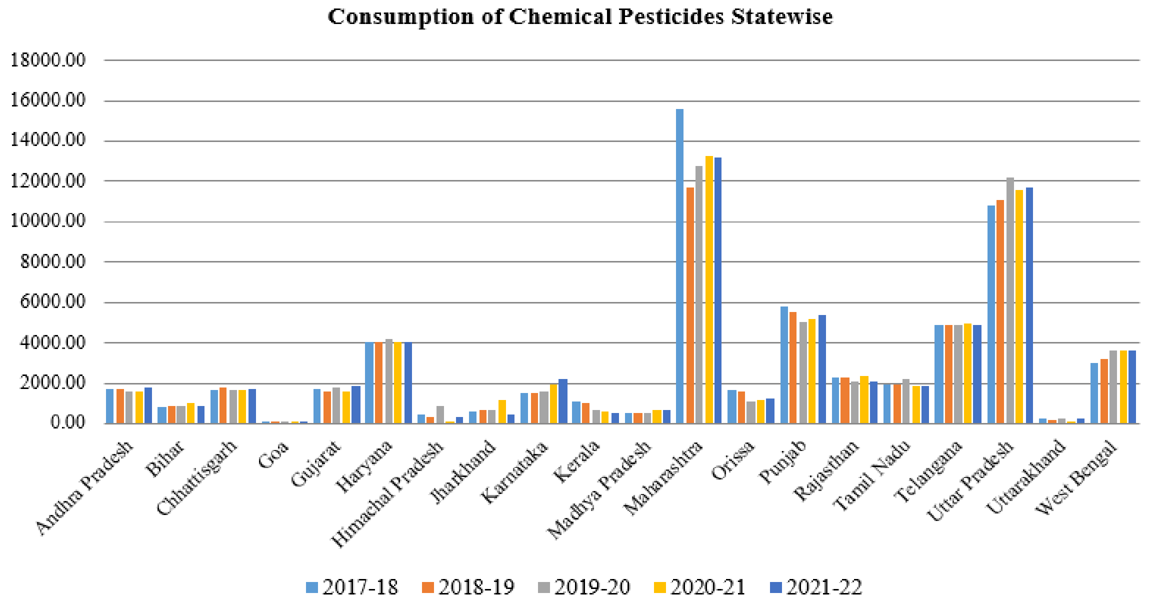


**Figure 4.** Consumption of Chemical pesticidesstate-wise [40]

*Plant-based biopesticide:* Plant-based biopesticide is gaining wide popularity due to its easy availability and minimal side effects. The plants and some insects exhibit offensive and defensive strategies due to their co-existence on the earth for approximately three and a half million [41]. The strategy behind plant-based biopesticides is to be highly toxic against insects [16]. Some reported and registered plant-based biopesticides are such as Neem, pyrethrins, limonene, rotenone, sabadilla, karanj, Turmeric, garlic, Aristolochia, ginger, *Agave americana*, *Vitex negundo*, gliricidia, castor, custard apple, Datura, Calotropis, Ipomoea, and coriander to control and repel crop pests. Apart from these, many more are described in detail in **Table 2** having pesticidal activity against different types of insects [42, 43].

**Table 2.** Plants based biopesticides

| S. No. | Plants used as a biopesticide | Common name and Family | Pharmacological action | Reported Activity | References |
|---|---|---|---|---|---|
| 1. | ***Polygonum hydropiper* L. (Stem extract)** | Water pepper, Marshpepper, Machoi **Family:**Polygonaceae | It exhibits bitter, diuretic, stimulant, tonic, carminative, anthelmintic, hemostatic, emmenagogue, and lithotripter properties. | Its ethyl acetate extract of stem exerts 93% and 96 % mortality against *Sitophilus oryzae* adults after 12 hours and 24 hours, respectively | [44] |
| 2. | ***Annona squamosa* L. (Seed extract)** | Custard apple **Family:** Annonaceae | anti-malarial, anti-diabetic, hepatoprotective, antitumor, anti-bacterial, wound healing activity, anti-ulcer, anthelmintic, insecticidal, anti-microbial, anti-HIV, anti-oxidant activity, anti-arthritic, anti-inflammatory, analgesic activity | The insecticidal activity of custard apple was determined in petroleum spirit, ethyl acetate, methanol, and acetone against Raj, FSS II, CTC-12, and CR 1 strain of red flour beetle and *Tribolium castaneum* (Herbst). The petroleum spirit exerts the highest toxicity in the CTC-12 strain and the minimum toxicity found in acetone extract against the CR 1 strain. | [45] |
| 3 | ***Clerodendrumviscosum* Vent. (Root, leaf, and stem extract)** | Glory flower, Indian bhant tree, Bharangi **Family:** Verbenaceae | Cure many diseases such as headache, toothache, rheumatism, swelling, skin diseases, fever, diabetes, malaria, burns, tumors and epilepsy. Various scientific data are available showing various pharmacological properties of the plant, such as antibacterial, antioxidant, analgesic, healing, anti-venom, hepatoprotective, anti-inflammatory, antipyretic, anthelmintic, insecticidal, thrombolytic and cytotoxic. | The insecticidal activity of root, leaf, and stem extract of *C.viscosum* against *T. castaneum*andthe results showed highest mortality by stem extract (88% and 48%, LC value was 0.25 and 0.42 mg/ml at 72 h and 24 h) and the leaf extract showed least toxicity (56% and 28% mortality with 1.65 and 2.94 of LC value) than the stem and root extracts respectively at 72 h and 24 h of exposure. | [46, 47] |
| 4. | ***Argyreia speciosa* L.** | Sumudrashok, Elephant Creeper, Avegi, Chagalantri **Family:** Convolvulaceae | Ethano-pharmacological data revealed its anti-microbial, antidiarrhoeal, hepatoprotective, nootropic, anticonvulsant, CNS stimulant, hypoglycemic, anti-oxidant, anti-bacterial, antiviral, nematicidal, aphordiasic, analgesic, immunomodulatory, anti-inflammatory activity. | No reported scientific data against any pesticide effect is available, but *A. speciosa* traditionally claims pesticide activity. | [48] |
| 5. | ***Leucas aspera* (Wild) L.** | Thumbai, Tamba, Kubo, Dronpushpi **Family:** Lamiaceae | The scientific reports exhibited various pharmacological activities like antipyretic, anti-fungal, anti-oxidant, anti-microbial, antinociceptive, analgesic, anti-diarrheal, insecticidal, anti-inflammatory, and cytotoxic activity. | The plant showed anti-mosquito activity of aqueous, ethanol, methanol, chloroform and petroleum ether extracts of Leucasaspera against Aedesaegypti, Anopheles stephensi and Culexquinquefasciatus. The results showed that the mortality rate of 4-year-old Ae larvae was concentration dependent. aegypti, An. Stephensi and Cx. Quinquefasciatus. | [49, 50] |

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| 6. | ***Lippiajavanica L.*** | Fever tea, Sagwan, Musukudu **Family:** Verbenaceae | Ethno-medicinal data revealed its uses in colds, coughs, fever, malaria, wounds, diarrhea, chest pains, bronchitis, and asthma. Also, scientific studies showed numerous pharmacological activities such as anti-cancer, antiamoebic, anti-diabetic, anti-malarial, anti-microbial, anti-oxidant, antiplasmodial, and pesticidal effects. | The plant exhibits lots of pesticidesagainst the free-living nematode *Caenorhabditis elegans.* Another research exhibits activity against *Aedes aegypti* larvae and *Sitophilus zeamais* (maize weevil). Some reports revealed its natural pesticidal effect (53.2%) against the aphid species *Brevicoryne brassicae.*The scientific data revealed that its leaf extract showed pesticidal results against rape (*Brassica napus* L.) and tomato (*Solanum lycopersicum* Lam.), red spider mites, and *Tetrany chusevansi (63%).* Hence, the scientific findings indicated its potential nematicidal and plant growth-promoting properties. | [51, 52] |
| 7. | ***Tephrosia vogelii*** | Fish poison bean, Wild indigo, Sharpunkha **Family:** Fabaceae | The plant exhibits numerous pharmacological activities likeanti-diabetic, anti-ulcer, anti-diarrheal, wound healing, anti-inflammatory, insecticidal, antiviral, anti-protozoal, anti-fungal, anti-plasmodial, and many other activities. | The flowers of *Tephrosia vogelii* were scientifically researched with essential oil to control the aphid *Cerosipha forbesi* in the strawberry crop**.** During the experiment, the essential oil exhibitedconcentration-dependent mortality of aphid *C. forbesi*. LC50 and LC90 of the insect population at 0.106 and 0.380 mL/L, respectively. | [53, 54] |
| 8. | ***Tithonia diversifolia*** | Sunflower, Mexican Sunflower, Bolivian Sunflower, Tree Marigold **Family:** Asteraceae (Compositae) | The plant traditionally and scientifically reported various pharmacological activities like anti-inflammatory, antinociception, analgesic, anti-diarrheal, anti-malarial, anti-bacterial, anti-oxidant, antihyperglycemic, and cancer chemopreventive activities due to the presence of different active constituents. | The insecticidal activity of *Tithoniadiversifolia* wastested against the pest of stored legumes named cowpea beetle, *Callosobruchus maculates.* The extracts were prepared and fractioned in 10, 1, and 0.1% w/v representative concentrations. Extracts were found toxic to recently emerged adults but did not reduce oviposition by those females that survived. | [55, 56] |
| 9. | ***Vernonia amygdalina*** | Bitter leaf **Family:** Asteraceae | V.amygdalinaethnobotanicaland scientifically reported to possess several pharmacological effects like anti-microbial, anti-malarial, antithrombotic, anti-oxidant, anti-diabetic, laxative, hypoglycemic, antihelmintic, anti-inflammatory, cathartic, anti-cancer, antifertility, anti-fungi, anti-bacterial. | The insecticidal activity ofVernonia amygdalinawastested against the pest of stored legumes named cowpea beetle, *Callosobruchus maculates.* The extracts were prepared and fractioned in 10, 1, and 0.1% w/v as representative concentrations. Extracts were found toxic to recently emerged adults but did not reduce oviposition by those females that survived. The sesquiterpin compound tagitinin A was isolated from active fractions, identified using H1 and C13-NMR, and shown to be toxic to *C. maculates*. | [42, 57] |

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| 10. | ***Bidens pilosa* L.** | Black-jack, burr marigold, or Spanish needle **Family:** Asteraceae. | The plant exhibits astringent, diaphoretic, and diuretic properties. Roots, leaves, and seeds possess anti-bacterial, anti-dysenteric, anti-inflammatory, anti-malarial, anti-septic, anti-cancer, antipyretic, liver-protective, blood-lowering, hypoglycemic, diuretic, anti-diabetic, and hepato-protective effects, antifeedant activity. | The antifeedant activity of methanolic extract of weedy plant B. pilosa was tested against three stored grain pests, Oryzaephilussurinamensis, Sitophilus oryzae, and Acanthoscelidesobtectus, at three different concentrations 3,5 and 7%. The results revealed that it exhibits the highest feeding deterrence indices (FDI) against A. obtectus at the three tested concentrations compared to neem oil. | [58-60] |
| 11 | ***Lantana camara*** | Raimuniya; Spanish Flag, Wild sage **Family**: Verbenaceae | anti-bacterial, anti-oxidant, antipyretic, insecticidal, hypoglycemic, cardiovascular, anti-microbial, wound healing, diaphoretic, carminative, antispasmodic, tonic, antiemetic, to treat respiratory infections, and disorders (cough, cold, asthma, and bronchitis), in the treatment of tetanus, epilepsy, dysentery, and gastropathy,antiurolithiatic, hepatoprotective, antihemorrhoidal, thrombin inhibition | Petroleum and methanolic extract of the aerial part of the plant showed 10-43% insecticidal, antiovipositional, and antifeedant activity against *Callosobruchuschinensis* at 1-5% conc.<br>Another study tested the insecticidal activity of methanol, ethanol, and ethyl acetate extracts of Lantana camara leaf oil and powder against maize weevils, Sitophilus zeamais. The results showed repellency and mortality were based on time and concentration dependence. | [61-66] |
| 12 | ***Agave Americana*** | century plant, maguey, or American aloe **Family**: Asparagaceae | The plant showed anti-microbial activity against *Staphylococcus aureus, Shigella, Klebsiella pneumoniae, E. coli, Bacillus thuringiensis, Salmonella paratyphi*, anti-oxidant and anti-cancer activity. | The insecticidal activity of *Agave americana* leaf extractswasevaluated against the adults of *S. oryzae*. The results revealed that LD50, LC50, and RC50 values were 10.55 µg/insect, 8.99 µg/cm2, and 0.055 µg/cm2 for topical application, treated filter paper, and repellent bioassay, respectively. | [67, 68] |
| 13 | ***Gliricidia sepium*** | mouse killer, **Family**: Fabaceae | coughs, asthma, urticaria, rash, burns, scabies, dermatitis, functioning as an anti-pruritic on the skin, treating bacterial and protozoal infections,among some reported activities are cytotoxic, anti-microbial, anti-bacterial, anti-inflammatory, anti-oxidant, thrombolytic, anti-sickling, wound healing, larvicidal activity, and anthelmintic activity | The plant showed nematicidal against Meloidogyne incognita nematode and mosquito repellent activity against Aedes aegypti; the maximum repellency was 78% compared with the citronella oil in ethanol extract of leaves. | [69-71] |
| 14 | ***Vitex negundo* L.** | Nirgundi and five-leaved chaste trees. **Family**: Verbenaceae | The plant claims following pharmacological action such as tonic, febrifuge and expectorant, otalgia, arthritis, dyspepsia, colic, rheumatism, leprosy, verminosis, flatulence, dysentery, urinary disorders, wounds, ulcers, bronchitis, cough, malarial fever, hemorrhoids, dysmenorrhoea, leprosy, skin diseases and general debility, antidote to snake venom. | The plant elucidatesthe insecticidal activity of stem bark extract of nirgundi against the red flour beetle, *Tribolium castaneum*. The activity was tested in methanol, pet ether, acetone, and ethyl acetate on both adult and larval insects. The degree of toxicity was found to be in MeOH>Pet spt.>acetone>EtOAc. | [72, 73] |

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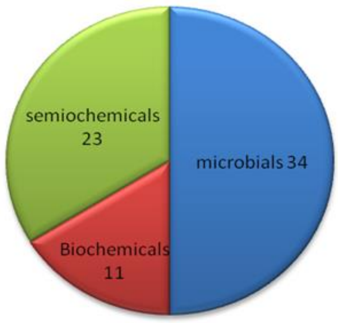
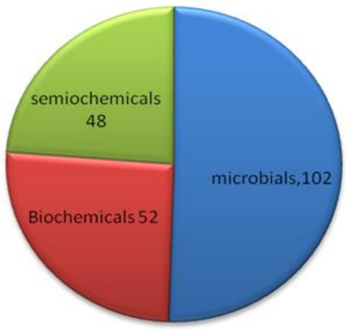
| 15 | ***Aristolochia indica* L.** | Kirmar, Garudakkodi Indian birthwort, Ishar-mul **Family**: Aristolochiaceae | The plant is used in treating dry cough, joint pain, inflammation, biliousness, dyspnoea of children, snake bites, and also as abortifacient. The in-vitro research studies on the anti-snake venom, larvicidal, and anti-oxidant properties have been proved. | The antifeedant and larvicidal activity was tested in silver nanoparticles of A. indica against third instar larvae of Helicoverpaarmigera and HeLa cell lines. The maximum antifeedant and larvicidal efficacy was observed in crude aqueous and synthesized Ag NPs against H. armigeralarvae (LC50 = 127.49, 84.56 mg/L; 766.54, and 309.98 mg/mL), respectively. The extract of A.indica and Ag NPs elicited a low cytotoxic effect with TC50 values of >100 and 89 µg/mL, respectively. | [74-76] |

*Global and Indian market perspective of biopesticide*

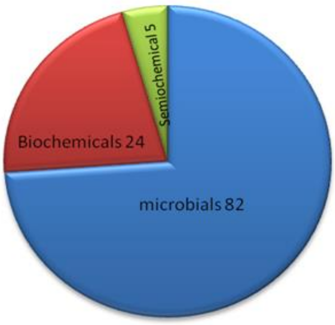
Despite the market scenario of synthetic pesticides, the biopesticide market has gained wide popularity due to playing a more prominent role in the safety of the environment and cost-effectiveness. The global biopesticide market spread nearly $ 7.7 billion in 2021 [77-79]. According to the report, 1400 biopesticide products are in the market overall. The pie chart **(Figure 5)** described that in the European Union, a total of 68 biopesticide products are registered, which 34 microbial, 11 biochemical, and 23 semiochemicals [80]; the database of the USA revealed 202 biopesticide products in which 102 microbial 52 biochemical and 48 semiochemicals are reported [10]. The researchers estimated the global biopesticide market reaches a 16 percent annual growth rate compared to synthetic pesticides [81].




a) Registered Biopesticide in EUP




b) Registered biopesticide in the USA




c) Registered biopesticide in India

**Figure 5.** Schematic Representation of Registered Biopesticide in Europe, USA, and India [80, 82, 83]

In India, the majority of the population relies on farming as a survival resource, and most of the people fulfill their needs through agriculture. Due to the use of synthetic pesticides, the health of people and animals decreases gradually, so people have focused on organic farming and biopesticides. However, its implementation requires a certain level of education. For the betterment of the Indian agro-ecosystem, the government of India passed the Insecticidal Act 1968, in which only 15 types of biopesticides are registered till now as described in the pie chart **(Figure 5)**. In India, biopesticides have only a 5% market than synthetic pesticides because of the lengthy and tough procedure of registration of biopesticides. So there is an immense need to simplify the regulation and registration process of biopesticide and to encourage the use of biopesticide in India for manufacturing and quality control training, organization of educational programmers, laboratory research and preparation, training to farmers for the exploration of biopesticide proficiency and ease of registration and regulation. There is a requirement for some legislative recognition in the Indian and Global market to achieve environmental safety and creates attentiveness among farmers, manufacturers, policy makers, government agencies, and the public to use biopesticide for pest management programs [3].

According to recent data, Pesticide market growth will increase by $549.34 million during 2023-2027. Also, the CAGR of the pesticide market is expected to grow at 4.08% during 2023-2027. In India, this rate is expected to rise from USD 69.62 million in 2022 to USD 130.37 million by 2029, exhibiting a CAGR of 9.38%. (Fortune Business Report 2022). The key factors driving the pesticide market growth are:

- Increased use of herbicides
- Expanding applications of nano-insecticides

## CONCLUSION

Biopesticides are proven to be better alternatives to synthetic pesticides. The researchers provide various biopesticides, including viable microorganisms, allelochemicals/semiochemicals, plant secondary metabolites, and genetically modified plant protectants to minimize the need for current environmental hazards. The advanced technology of nanopesticide encapsulation and Genetic engineering could be a more prominent, target-specific, and environmentally friendly approach. Using biopesticide produces quality crops with high yields, protecting the air, soil, water, animals, and humans from the hazardous effects of chemical pesticides. The plant-incorporated protectants and pheromones still required much effort in pest management techniques. The researchers need to be more focused on improving existing technology and implementing novel techniques in plant protection from insects, weeds, parasites and harmful microorganisms to provide safe, efficient, and cost-effective biopesticides.

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