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Review

A review on efficacy of biopesticides to control the agricultural insect's pest

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The excessive and inappropriate use of agrochemicals has undeniably resulted in adverse and sometimes irreparable effects on the environment including human health. The application of agrochemical caused contamination of soils, agricultural crops and groundwater. In the same way, dependence on chemical pesticides to manage pest problems has aggravated environmental decline and caused serious health effects on agricultural employees and rural communities. Pesticide residues also raise food safety concerns among domestic consumers and pose trade impediments for export crops. Moreover, agrochemical significantly accumulated in plant parts and affected the morphological, anatomical, physiological and biochemical processes of the plants and as such result to reduction in the yield of agricultural crops. Therefore, the need to feed an ever-increasing global population combined with increasing demand for sustainable agricultural practices has fueled a significant rise in demand for biopesticides. Biopesticides offer unique benefits all along the food value chain, providing additional options for growers, buyers, dealers, consultants and retailers. In this paper, the application of biopesticides as green chemicals to control the agricultural pest to maintain the sustainability in the agricultural production was discussed.

Key words: Agricultural pest, agrochemicals, biopesticides, green chemicals.

INTRODUCTION

Crop protection has immensely contributed to the success of Green Revolution and sustained production of food, fiber, fodder and feed (Singh et al., 2009; Bhushan et al., 2011). Due to intensification of agriculture, loss of biodiversity and dependence on monocropping, etc., biotic stresses due to pests and pathogens have increased (Anastas and Warner, 1998; Parmar, 2010; Anna et al., 2011). During the last four decades of chemicalisation in agriculture, Green Revolution has helped in managing many pests and diseases, but their application is said to have resolved several problems like pesticide residues in food stuff, environmental pollution, imbalance of ecological equilibrium, and resurgence of minor pests and pathogens (Anonymous, 2009; Mukherjee et al., 2013). In addition to that, management of pests, a term which includes insects, pathogens, weeds and rodents, etc., will continue to play a critical role in sustaining production and productivity in Indian agriculture. The use of synthetic chemical pesticides had been increased widely for reducing the estimated 45% gross crop loss due to pests and diseases, amounting to around Rs. 290 billion per annum (Husain and Khatun, 2005; Ansari et al., 2012; Gupta et al., 2013). More and more quantities of chemicals are used for agricultural intensification to feed an ever growing population. In fact, the pest induced loss is on the rise despite increasing usage of pesticides. Fortunately, realization of the negative effects of these chemicals on nature and on natural resources like pollution, pesticide residue, pesticide resistance, etc., have forced many to shift focus to more reliable, sustainable and environment friendly agents of pest control, the biopesticides. In spite of the claimed efficacy, their use, however, has remained very low due to a number of socio-economic, technological and institutional constraints (Chattopadhyay et al., 2004; Azamal, 2006; Chandler et al., 2011). Nonetheless, rise in income levels due to a growing economy coupled with increasing awareness of health related effects of chemical pesticides has increased the demand of organic food. In view of this demand and the government's efforts to mitigate climate change, biopesticides are going to play an important role in future pest management programmes (Sinha and Biswas, 2008; Gupta et al., 2013).

Likewise, organic farming has emerged as an important priority area globally in view of the growing demand for safe and healthy food and long term sustainability and concerns on environmental pollution associated with indiscriminate use of agrochemicals (Blondell, 1997; Hall and Menn, 1999; Harris and Dent, 1999; Bhushan et al., 2011). Though the use of chemical inputs in agriculture is inevitable to meet the growing demand for food in the world, there are opportunities in selected crops and niche areas where organic production can be encouraged to trap the domestic export market. The other important problem caused by the excessive and inappropriate use of chemical pesticides concerns the presence of pesticide residue in food (Fishel, 2006; Ritter, 2009; Yankanchi and Gadache, 2010). Many of the pesticides currently being used have a tendency to survive in plants for a long time and they also go into the food chain. The problem of pesticide residue is already a serious threat to environment and human health. It is clear that the excessive use of chemical pesticides in agriculture is a serious cause of concern. It is therefore important that alternative environmental friendly methods of plant protections are adopted, such as integrated pest management (IPM) techniques, including the use of biofertilizers and biopesticides (Desai et al., 1997; Dhakshinamoorthy and Selvanarayana, 2002; Venkatashwarlu, 2008; Kawalekar, 2013).

RESEARCH METHODOLOGY

In the present review, secondary data were exploited based on literature review of e-journals, seminar proceedings, company literature, published reports and government publications. The literature has been collected using the Departmental Library of the Department of Zoology and Environmental Science, of the Gurukula Kangri University. The research papers have been downloaded from different sources like Springer, Elsevier, Taylor and Francis journals in the e-library provided by the University Grants Commission, New Delhi, India.

PEST AND PESTICIDES

Unanimously, a pesticide is any substance used to kill, repel, or control certain forms of plant or animal life that are considered to be pests (USEPA, 2008; Kawalekar, 2013). The pesticides include herbicides for destroying weeds and other unwanted vegetation, insecticides for controlling a wide variety of insects, fungicides used to prevent the growth of molds and mildew, disinfectants for preventing the spread of bacteria, and compounds used to control mice and rats. Because of the widespread use of agricultural chemicals in food production, people are exposed to low levels of pesticide residues through their diets. Pest management techniques have evolved over the past 50 years (Salas, 2001; Kovach et al., 2004; USEPA, 2008; Kawalekar, 2013). Inorganic chemical pesticides were replaced by synthetic organic chemicals, and now biopesticides constitute a significant part of pest management technology. While conventional chemicals will remain as important pest management components, and the processes of combinatorial chemistry and high-throughput bioassays will allow the rapid synthesis and testing of large numbers of candidate compounds, the new and equally important tools in pest management, with microbial pesticides and transgenic crops are likely to play important crop protection roles (Krischik and Davidson, 2007; Prabhat et al., 2014). Misuse and incomplete understanding of the environmental fate of many industrial practices involving chemicals has resulted in environmental problems. Agriculture has been identified as the largest non point source of water pollution, but it can also provide methodologies to even prevent pollution. In their contribution, agricultural green chemistry is in process of bioremediation of organic waste-containing aqueous solvents (Mukhopadhyay, 2004; Singh et al., 2009; Prabhat et al., 2014).

Pesticides are the only toxic substances released intentionally into our environment to kill living things. This includes substances that kill weeds (herbicides), insects (insecticides), fungus (fungicides), rodents (rodenticides), and others. The use of toxic pesticides to manage pest problems has become a common practice around the world (Lewis et al., 1997; Nathan et al., 2006; Krischik and Davidson, 2007). Pesticides are used almost everywhere not only in agricultural fields, but also in homes, parks, schools, buildings, forests, and roads. It is difficult to find somewhere where pesticides are not used from the can of bug spray under the kitchen sink to the airplane crop dusting acres of farmland; our world is filled with pesticides (Mishra, 1998; Pavela, 2007; Greaves and Grant, 2011). In addition, pesticides can be found in the air we breathe, the food we eat, and the water we drink. Pesticides have been linked to a wide range of human health hazards, ranging from short-term impacts such as headaches and nausea to chronic impacts like cancer, reproductive harm, and endocrine disruption (Nelson, 2004; Sinha and Biswas, 2008; Venkatashwarlu, 2008; Kawalekar, 2013). The pesticides produce two types of effects in the living environment.

Acute effects

Acute effects are short term or immediate effects and they include nerve, skin, and eye irritation and damage, headaches, dizziness, nausea, fatigue, and systemic poisoning - which can sometimes be dramatic, and even occasionally fatal.

Chronic effects

The chronic effects are long term effects and may occur years after even minimal exposure to pesticides in the environment, or result from the pesticide residues which we ingest through our food and water.

BIOPESTICIDES

Generally, biopesticides are pesticides derived from natural substances or materials such as animals, plants, bacteria, and minerals. The biochemical pesticides introduced include insect pheromones, plant extracts and oils, plant growth regulators and insect growth regulators (Jarvis, 2001; Kalra and Khanuja, 2007; Gupta and Dikshit, 2010). Microbial pesticide includes bacteria, virus, fungus, and other less common microorganisms. The most common benefits of biopesticides are less toxicity, quick biodegradability and target to specific pest, maintain ecological balance, etc (Rahaman and Motoyama, 2000; Venkatashwarlu, 2008; Bhushan et al., 2011).

The field of biopesticides is deep; consequently they are a source of both optimism and concern. There is a tremendous amount of work and research occurring in this field, but like other green chemistry solutions, developing safe, effective biopesticide products requires holistic thinking and multi-disciplinary approaches to establishing safety, which is a challenge for the biopesticide industry (Mukhopadhyay et al., 1992; Kalra and Khanuja, 2007; Prabhat et al., 2014). Interestingly, it is important to note that biopesticides fall along a spectrum of toxicity. At one end are products that are extremely narrow in focus (for example, targeting a single species in a specific window of its life cycle). At the opposite end are biopesticide products that are wider in effect. When highly specified, biopesticides can be almost utterly benign in their human and environmental effects. When their impact is broader, however, biopesticides raise some of the same human and ecosystem impact concerns of those conventional pesticides (Gelernter, 2006; Nerio et al., 2009; Byrappa et al., 2012).

In the biopesticides manufacturing process, the bacteria or fungal organisms are mass-produced using either a submerged liquid fermentation or solid-substrate (microbes produced on a solid food source) fermentation process. Fermentation processes can be highly specific to a bio-pesticide organism, and are often developed in a custom designed medium (Rahila et al., 2003; Petel et al., 2004; Venkatashwarlu, 2008). The process involves monitoring dissolved oxygen, pH and propagule (reproductive spore cells) production. For commercialization, it will be imperative to scale up production to a level where it is economically feasible. Formulations create an end product by blending the microbial component with carriers and adjuvants for better protection from unfavourable environments, enhanced survival of the bio-agent, controlled rates of release, as well as improved bioactivity, shelf life, and stability (Figure 1).

SCOPE OF BIOPESTICIDES

More likely, the pesticides are of biological origin (that is, viruses, bacteria, pheromones, plant or animal compounds are known as biopesticide), or simply origin of the active ingredient of a biopesticide is natural not synthetic (Umrao and Verma, 2002; Singhal, 2004; USEPA, 2008). They are highly specific affecting only the targeted pest or closely related pests and do not harm humans or beneficial organisms, while chemical pesticides are broad spectrum and known to affect non-target organisms including predators and parasites as well as humans. The striking feature of biopesticides is environment friendliness and easy biodegradability, thereby resulting in lower pesticide residues and largely avoiding pollution problems associated with chemical pesticides (Rabindra, 2005; Thakore, 2006; Greaves and Grant, 2011). Further, use of biopesticides as a component of integrated pest management (IPM) programs can greatly decrease the use of conventional (chemical) pesticides, while achieving almost the same level of crop yield. However, effective use of biopesticides demands understanding of a great deal about managing pests especially by the end users (Sinha and Biswas, 2008; Karen et al., 2009).

In terms of production and commercialization also, biopesticides have an edge over chemical pesticides like low research expenditure, faster rate of product development as well as flexible registration process (Mensink and Scheepmaker, 2007; Prabhat et al., 2014). The biopesticides market is growing very rapidly. In 2005, biopesticides accounted for about 2.5% of the total pesticide market, which was merely 0.2% during 2000. This share is expected to grow to about 4.2% by 2010, while the market value is estimated to reach more than US$ 1 billion. However, the overall growth rate of biopesticides is estimated to be about 10% per annum for the next 5 years (Singhal, 2004; Sinha and Biswas, 2008).

TYPES OF BIOPESTICIDES

The biopesticides are certain types of pesticides derived from such natural materials as animals, plants, bacteria, and certain minerals (USEPA, 2008; Greaves and Grant, 2011). The Environment Protection Agency (EPA) separates biopesticides into three major classes based on the type of active ingredient used, namely: microbial,

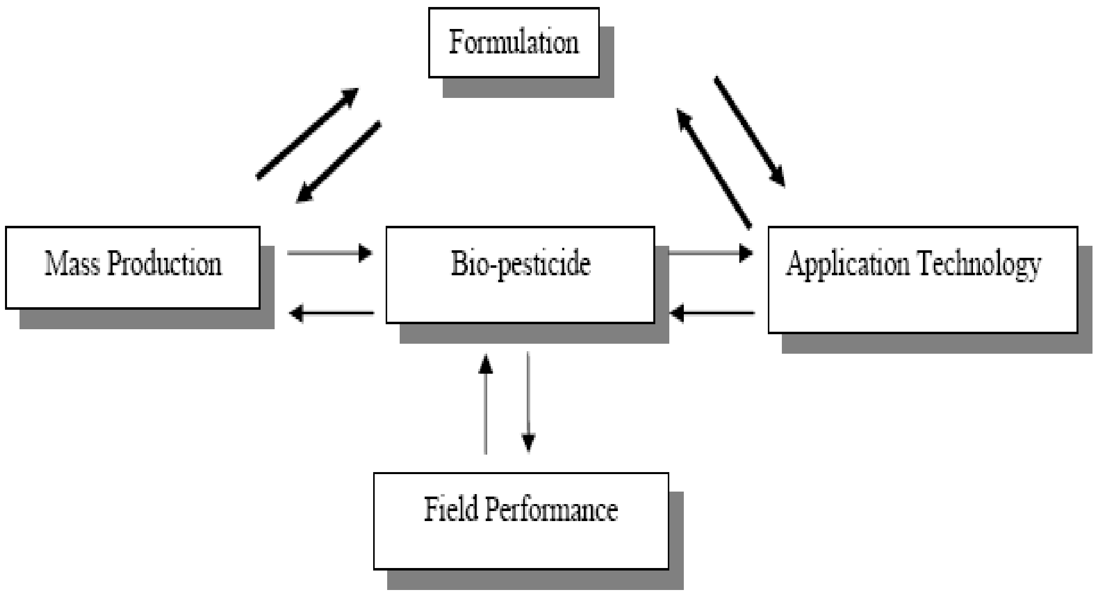

Figure 1. The model of biopesticides (Source: http://www.agriculture.gov.sk.ca/).

biochemical, or plant incorporated protectants (GMOs) (USEPA, 2008; Karen et al., 2009; Greaves and Grant, 2011).

(a) Biochemical pesticides:

1. Insect pheromones;
2. Plant extracts and oils;
3. Plant growth regulators;
4. Insect growth regulators.

(b) Microbial pesticides:

1. Bacterial biopesticides;
2. Fungal biopesticides;
3. Viral biopesticides;
4. Other microbial biopesticides.

(c) Biopesticide formulations.

Biochemical pesticides

The biochemical pesticides are the most closely related category to conventional chemical pesticides. Biochemical pesticides are distinguished from conventional pesticides by their non-toxic mode of action toward target organisms (usually species specific) and their natural occurrence (Gelernter, 2006; Ritter, 2009; Greaves and Grant, 2011). The active ingredient can be a single molecule or a mixture of molecules, such as a naturally occurring mixture comprising a plant essential oil, or a mixture of very structurally similar molecules called isomers in the case of insect pheromones. While all active ingredients of biochemical pesticides occur in nature, the active ingredient in the product may be a synthetic analogue to the naturally occurring substance. This is often necessary to make a viable product and/or process, such as with insect pheromones. As many of the active ingredients in this category of biopesticides are synthetic, the full range of green chemistry principles should be applied to the development of the active ingredient and the biochemical pesticide product (USEPA, 2008; Karen et al., 2009).

Insect pheromones

The insect pheromones are chemicals used by an insect to communicate with other members of the same species. Structurally, these chemicals are often very similar to substances used in flavors and fragrances. The pheromones are a subset of a broader category called semiochemicals. A semiochemical is defined as a message-bearing substance produced by a plant or animal, or a synthetic analogue of that substance, which evokes behavioral response in individuals of the same or other species (USEPA, 2008; Nerio et al., 2009; Chandler et al., 2011). The semiochemicals are used for various functions including attracting others to a known food source or trail, locating a mate, or sending an alarm. Insect sex pheromones are used in pest management. The insect pheromones themselves do not kill a target pest. When used for pest management, two common uses are to attract an insect to a trap containing a lethal pesticide or to disrupt mating. With mating disruption, proportionately large concentrations of the sex pheromones are present in the air, thus confusing the males and decreasing their success at locating a female with which to mate. The pheromones can also be used to monitor pest populations as part of larger integrated pest management (IPM) systems, particularly to determine appropriate timing and application of pesticides (Thakore, 2006; USEPA, 2008; Karen et al., 2009).

Plant extracts and oils

The plant extracts and oils are specific chemicals or mixtures of chemical components derived from a plant. This category of biopesticides is much more diverse in composition, target pest, and mode of action than insect pheromones discussed above (Kovach et al., 2004; USEPA, 2008; Byrappa et al., 2012). The plant extracts and oils are most often used as insecticides, but can also be used as herbicides. The mode of action varies greatly from product to product. Where sex pheromones directly interrupt the reproductive cycle of insects, plant extracts and oils often act less directly and specifically. Some botanical extracts such as floral essences attract insects to traps. Others such as cayenne can be used as deterrents. Others, such as lemongrass oil, strip the waxy coating off leaves of weeds to cause dehydration. Others coat the pest causing suffocation, and still others enhance the natural immune system of a crop (Karen et al., 2009; Kawalekar, 2013).

Plant growth regulators

The plant hormones and plant growth regulators are chemicals that alter the growth of a plant or plant part, or promote certain biological changes in the plant. Plants produce hormones naturally, while humans apply growth regulators to the plants (Mensink and Scheepmaker, 2007; USEPA, 2008; Karen et al., 2009). The plant growth regulators may be synthetic compounds (for example, IBA and Cycocel) that mimic naturally occurring plant hormones, or they may be natural hormones that were extracted from plant tissue (for example, IAA). According to the Florida Department of Agriculture and Consumer Services, a plant growth regulator is defined as any substance or mixture of substances intended, through physiological action, to accelerate or retard the rate of growth or maturation or for otherwise altering the behavior, of ornamental or crop plants, or the produce thereof, but does not include substances intended as plant nutrients, trace elements, nutritional chemicals, plant inoculants, or soil amendments (Fishel, 2006; Pavela, 2007; Yankanchi and Gadache, 2010).

Insect growth regulators

The insect growth regulators are chemical compounds that alter the growth and development of insects. Thus, they are specific to the control of insect pests. There are three key types of insect growth regulators, each with a distinct mode of action. Juvenile hormone-based insecticides disrupt immature development and the emergence of an adult. Precocenes interfere with normal function of the glands that produce juvenile hormone, thereby indirectly preventing the emergence of a reproductive adult (Husain and Khatun, 2005; Yankanchi and Gadache, 2010). Chitin synthesis inhibitors limit the ability of the insect to produce a new exoskeleton after molting. Thus, chitin synthesis inhibitors leave the insect unprotected from the elements and from prey, drastically reducing its chances of survival (USEPA, 2008; Karen et al., 2009; Yankanchi and Gadache, 2010).

Microbial pesticides

The microbial pesticides come from naturally occurring or genetically altered bacteria, fungi, algae, viruses or protozoans. They suppress pests either by producing a toxin specific to the pest, causing disease, preventing establishment of other microorganisms through competition, or various other modes of action (Husain and Khatun, 2005; Mensink and Scheepmaker, 2007; USEPA, 2008). For all crop types, bacterial biopesticides claim about 74% of the market; fungal biopesticides, about 10%; viral biopesticides, 5%; predator biopesticides, 8%; and “other” biopesticides, 3% (Thakore, 2006). At present, there are approximately 73 microbial active ingredients that have been registered by the US EPA. The registered microbial biopesticides include 35 bacterial products, 15 fungi, 6 non-viable (genetically engineered) microbial pesticides, 8 plant incorporated protectants, 1 protozoan, 1 yeast, and 6 viruses (Karen et al., 2009; Kawalekar, 2013).

Bacterial biopesticides

The bacterial biopesticides are the most common form of microbial pesticides. They are typically used as insecticides, although they can be used to control unwanted bacteria, fungi or viruses as well. As an insecticide, they are generally specific to individual species of moths and butterflies, as well as species of beetles, flies and mosquitoes. To be effective, they must come into contact with the target pest, and may require ingestion to be effective (USEPA, 2008; Anna et al., 2011; Kawalekar, 2013).

Fungal biopesticides

The fungal biopesticides can be used to control insects, plant diseases including other fungi or bacteria, nematodes, and weeds. They are often parasitic or produce bioactive metabolites such as enzymes that dissolve plant walls. The mode of action varies and depends on both the pesticidal fungus and the target pest. *Beauveria bassiana* spores germinate, grow, and proliferate in the insect’s body, producing toxins and draining nutrients to cause insect death. *Trichoderma* is a fungal antagonist that grows into the main tissue of a disease-causing fungus and secretes enzymes that degrade the cell walls of the other fungus, then consumes the contents of the cells of the target fungus and multiplies its own spores (USEPA, 2008; Anonymous, 2009; Kawalekar, 2013).

Viral biopesticides

The baculoviruses (viral biopesticides) are pathogens that attack insects and other arthropods. Unlike other members of this category, they are not considered living organisms, but rather parasitically replicating microscopic elements (USEPA, 2008). Baculoviruses are extremely small and are composed primarily of double-stranded DNA required for the virus to establish itself and reproduce. Because this genetic material is easily destroyed by exposure to sunlight or by conditions in the host's gut, an infective baculovirus particle (virion) is protected by protein coat called a polyhedron (USEPA, 2008; Kawalekar, 2013). Two main families of baculoviruses include granulosis virus and nucleopolyhedrosis virus. They differ in the number and structure of the protective protein coat and are both relatively large and complex in structure in comparison to many other types of viruses (Figure 2).

Other microbial biopesticides

There are many other organisms which are also used as biological controls in integrated pest management systems (Kovach et al., 2004; USEPA, 2008). Protozoa are microscopic single-celled animal-like organisms rarely used as biopesticides. As of 2002, there was only one insecticidal protozoan registered with the EPA. Use of macroscopic predators such as live insect releases is also a common biological control strategy that can be very effective, but must be well managed to prevent ecological imbalances that can result from introducing insects into areas where they may have no natural predators. Macroscopic predators are not regulated as biopesticides, and are outside the scope of this study. Nematodes are microscopic worms that are typically parasitic and commonly used as insecticides (USEPA, 2008; Karen et al., 2009; Parmar, 2010).

Biopesticide formulations

A registered biochemical or microbial pesticide contains one or more active ingredients from the categories described above. The active ingredient(s) is primarily responsible for the pesticide claims. In addition to the active ingredient, the product formulation contains one to dozens of other ingredients called inerts. This term can be misleading, as it implies these components do not have a particular function or that they are benign from a human and environmental health perspective (Kovach et al., 2004; Nerio et al., 2009; Prabhat et al., 2014). On the contrary, inerts are very important components required to make an effective product and the toxicity profiles of inerts vary widely. Moreover, inert ingredients can have serious potential health and ecosystem impacts and can include endocrine disrupting chemicals, allergens and other chemicals of concern. In the case of biopesticides, this is problematic; a company can combine a highly targeted, benign active ingredient in a formulation that includes endocrine disrupting inert ingredients. From an environment and health perspective, this changes what might have been a deep green product into a product of concern (Karen et al., 2009; Nerio et al., 2009; Prabhat et al., 2014). During the recent past, various studies have been carried out to investigate the effects of different biopesticides on various pests in different agricultural crops. The details of these studies are as follows:

Rahman and Motoyama (2000) treated intact garlic clove, grated garlic and its volatile extract applied on brown rice had a repellent effect but no insecticidal activity against two stored product pests, the maize weevil (*Sitophilus zeamais*) and the red flour beetle (*Tribolium castaneum*). Neither repellency nor insecticidal activity was observed with garlic or its extract against two agricultural pests - larvae of the diamondback moth (*Plutella xylostella*) and green peach aphids (*Myzus persicae*). In comparative tests, hot pepper and 'wasabi' mustard had only weak repellency, although the volatile components of 'wasabi' mustard showed insecticidal activity against these insects. Volatile components of garlic were trapped and subjected to gas chromatography mass spectrometry (GC-MS) analysis. The four major peaks resolved were sulfide compounds produced by the rapid degradation of allicin and a cyclic compound produced by dehydration. It remains to be determined whether allicin itself, the degradation products, or their mixture are responsible for the repellent effect.

Salas (2001) evaluated the efficacy of garlic based repellent, commercially known as Garlic Barrier, at 500, 750 and 1000 ml/ha on the reduction of whitefly *B. tabaci* populations on tomato. The results showed that Garlic Barrier at 500 and 750 ml/ha recorded the greatest egg population reduction in comparison with endosulfan and the control (untreated plot). The same treatments showed the lowest nymph populations. Since adults of *B. tabaci* were able to pose and lay eggs on the leaves, Garlic Barrier acted as an oviposition suppressor or deterrent rather than a repellent. Dhakshinamoory and Selvanarayana (2002) studied the efficacy of some plant materials on the survival of *C. maculatus* infesting stored green gram. The treatment comprised leaves namely: neem, nochi, pongum, citrus and thulsi, fly ash, kitchen ash, castor oil and red earth, and 20 adult beetles were introduced in each container and kept covered with muslin cloth. The results at 7 days after treatment were highest (100%) in castor oil, followed by neem leaf

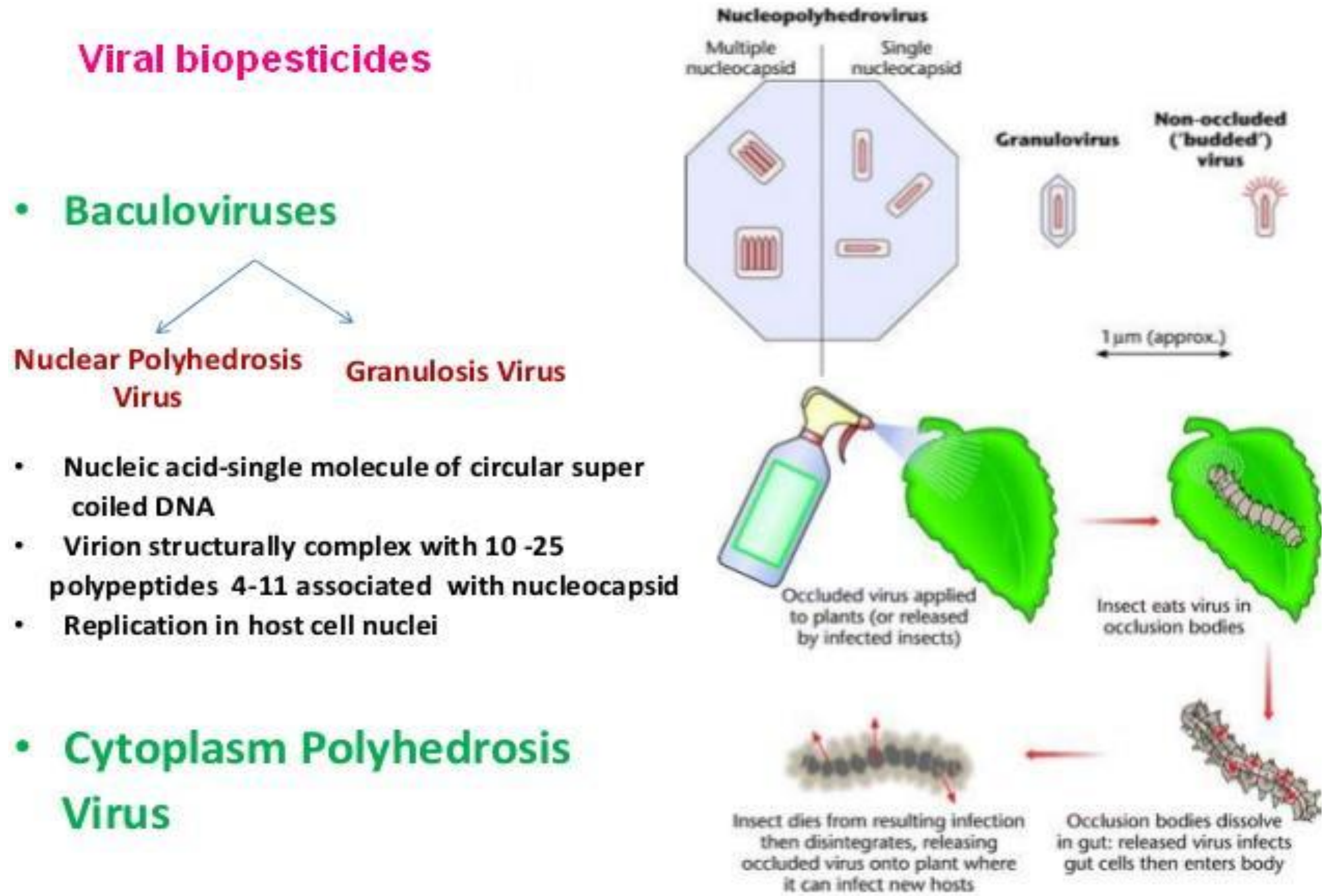

Figure 2. Viral biopesticides and their pest control mechanism (Source: www.sciencedaily.com).

powder (91.66%).

Umrao and Verma (2002) stated that the efficacy of various plant products, leaf powder of Dharek, *Melia azadirachta* and Sadabahar, *Ipomoea carnea* at 10 g/kg grain and oils of coconut, mustard and groundnut and neem products such as Ashok, Nimbicidine and neemgold at 1 ml/kg was assessed against pulse beetle, *Callosobruchus chinensis*, based on the percentage of grains damaged and percentage of weight losses. Nimbicidine and Ashok appeared to be the most effective in minimizing the damage by pests in grains (1.97 and 2.36%, respectively), followed by the Neemgold treatment (2.61%). The loss in weight was as high as 45.20% in the untreated grains, which considerably decreased to a level of 0.52, 0.93 and 1.07% by the application of Nimbicidine, Ashok and Neemgold, respectively. Rahila et al. (2003) collected neem oil samples obtained from neem seeds from Karachi, Hyderabad, Dokri, Shikarpur and Faisalabad in Pakistan and were evaluated for repellent effects against the red flour beetle, *T. castaneum*. All the samples of neem oil (22) proved to have promising repellent effects (showing more than 45% repellency at 600 µg/cm^2 application rates). The samples from Hyderabad and Shikarpur had promising repellent effects at 300 and 150 micro g/cm^2. Samples from Karachi (expeller extract) and Faisalabad had promising effects at 600 and 150 µg/cm^2. The highest average repellency of 52.25% after 8 weeks was exhibited by the Hyderabad sample at 600 µg/cm^2. At the same rate of application, the average repellency was 50.13 and 44.75% in Shikarpur and Dokri samples, respectively.

Petel et al. (2004) observed the effectivity of neem (*Azadirecta indica*), bergera (*Bergera koenigii*) akk (*Calotropis gigentia*), ipomoea (*Ipomia reptans*), garlic (*Allium sativum*), chilli (*Capsicum amanda*) and mustard (*Brassica campestris*) powders at three doses (1, 3 and 5 gkg^{-1} grain) for their efficacy against *Sitophilus oryzae* under free choice and no choice conditions. The mango ginger rhizome powder was the most effective treatment, hindering the orientation of the beetles, giving maximum mortality and reducing the emergence of the adults. Husain and Khatun (2005) reported the single effect of Biskatali (knotgrass) (*Polygonum hydropiper* Linn.) leaf power; however, its methanol extract and the combination of the extract and malathion on *Tribolium castaneun* Herbst larvae were investigated in the laboratory. There were some mortalities due to Biskatali (knotgrass) but were not very prominent. The LD50 value of malathion and Biskatali (knotgrass) was lowered when combined with malathion.

Nathan et al. (2006) studied and evaluated the effects of bacterial toxins (*Bacillus thuringiensis*) and botanical insecticides (*Azadirachta indica* and *Vitex negundo*) on lactate dehydrogenase (LDH) activity in *Cnaphalocrocis medinalis* (Guenée) (the rice leaf folder). Bacterial toxins and botanical insecticides affected the LDH activity individually and in combination. When they were combined, the effect was more severe at low concentration. There was a decrease in enzyme activity over controls at all concentrations tested. The combined effect of the three biopesticides resulted in a considerable decrease in enzyme activity, indicating strong enzyme inhibition. Clear dose response relationships were established with respect to enzyme activity. Pavela et al. (2007) studied the effects of extracts of neem (*A. indica*), garlic and *Eucallyptus hydrida*, *L. camara* and *V. negundo* against *R. dominica* on wheat in the laboratory. *A. indica*, *L. camara* and *V. negundo* were the most effective against the adult, though they reduced grain damage (number basis and weight basis).

Nerio et al. (2009) conducted an experiment where essential oils isolated from seven aromatic plants grown in Colombia were analyzed by gas chromatography–mass spectrometry (GC–MS) and evaluated them for repellent activity against *Sitophilus zeamais* (Coleoptera: Curculionidae) using the area preference method. Most oil components were oxygenated monoterpenoids or phenolic compounds. Six oils were repellent, with *Lippia origanoides* as the most active. *Eucalyptus citriodora* and *Tagetes lucida* were also repellant at doses between 0.063 and 0.503 μL/cm^2.

Yankanchi and Gadache (2010) reported that ethanol extract of *Clerodendrum inerme* L. (Verbenaceae), *Withania somnifera* L. (Solanaceae), *Gliricidia sepia* L. (Fabaceae), *Cassia tora* L. (Caesalpiniaceae) and *Eupatorium odoratum* L. (Asteraceae) were evaluated for their efficacy on mortality and progeny production of rice weevil, *Sitophilus oryzae* L. (Coleoptera: Curculionidae). Adult insects were exposed to the 2.5 and 5% extracts treated wheat, and mortality was assessed after 1, 2, 7, 14 and 21 days. Subsequently, all adults were removed and the treated grains remained at the same conditions for an additional 45 days. After this interval, the commodity was checked for progeny production. The beetles mortality in all extracts was increased in dose dependent manner. Results indicated that *C. inerme* and *W. somnifera* extracts were more effective than *G. sepia*, *C. tora* and *E. odoratum* against adult insects. Interestingly, the progeny production (Fl) was completely suppressed even in the lowest dose. It was concluded that both *C. inerme* and *W. somnifera* can be used for the protection of stored wheat from infestations of *S. oryzae*.

Anna et al. (2011) studied the two *Botrytis cinerea* isolates used in the experiment and observed that they responded differently to the fungicides applied. An isolate obtained from raspberry fruit infected by the fungus was more susceptible to the biopesticides as well as the fungicide Signum 33 WG. It was observed that the efficacy of the biopesticides differed; however, their efficacy, which depended on both the active ingredient and the duration of biopesticide influenced the mycelium. *B. cinerea* was rather resistant to the biological pesticides. The growth of both isolates was completely inhibited at a concentration that was fivefold higher than the recommended amount and the recommended concentration, but only at the initial stage of culturing. Of the biopesticides, Biosept 33 SL was most effective at controlling the growth of *B. cinerea*. No sclerotia were formed on media containing the biopesticide. Propolis also inhibited the production of spores; however, the biopesticide effectively controlled the development of mycelium only when applied at the highest rate. The synthetic fungicide Signum 33 WG is conventionally applied to control grey mould. Signum 33 WG was highly effective at controlling both the *B. cinerea* isolates.

Bhushan et al. (2011) reported that neem seed kernel extract (NSKE) was found most effective in reducing the larval population of *Helicoverpa armigera* in chickpea and pod damage. Neem formulations also have a significant effect against eggs of peach fruit fly *Bactrocera zonata* (Saunders). Over 195 species of insects affected by neem extracts and insects that have become resistant to synthetic pesticides are also controlled with these extracts. The apprehension that large scale use of neem based insecticides may lead to resistance among pests, as being observed with synthetic pesticides, has not been proven correct. Salma et al. (2011) also reported that neem biopesticides are systemic in nature and provide long term protection to plants against pests. Pollinator insects, bees and other useful organisms are not affected by neem based pesticides.

Byrappa et al. (2012) was carried out at the Agriculture Research Station, Balajigapade, and Chickaballapura district during kharif season 2009. The evaluated biopesticides were NSKE (5%), HaNPV (250 LE/ha), Bt (1kg/ha), neem oil (2%), Panchagavya (3%), Clerodendron + Cow urine extract (10%) and sequential spray of HaNPV-Bt -NSKE, Bt-NSKE-HaNPV and NSKE-HaNPVBt. FYM (9.5 t ha^{-1}) and bio-digester liquid (6,500 l ha^{-1}) were applied to organic plots. Sequential spray of insecticidal spray (Carbaryl-Endosulfan-Malathion) and recommended dose of FYM (7 t ha^{-1}), fertilizer (25:50:25 kg NPK ha-1) were applied to inorganic plot. Pod borers namely, *Helicoverpa armigera* (Hübner), *Maruca testulalis* Geyer, *Exelastis atomosa* Walshinghan, *Sphenarches caffer* Zeller, *Etiella zinkenella* (Treitschke), *Lampides boeticus* Linnaeus and *Adisura atkinsoni* Moore emerged as serious pests during cropping period. Sequential spray of insecticides carbarylendosulfan-malathion applied at 45, 55 and 70 DAG, respectively recorded less insect pest's abundance. Among biopesticides, sequential application of NSKE-HaNPV-Bt was effective against insect pests. HaNPV was effective against *H. armigera* larvae, but ineffective to other pod borers. Panchagavya and clerodendron + cow urine extract were ineffective in reducing the pod borer incidence. Among biopesticides treated plots, sequential application of NSKE-HaNPV-Bt recorded higher grain yield (10.01 qha^{-1}), whereas package of practices followed treatment (inorganic plot) recorded 11.37 qha^{-1} grains.

Gupta et al. (2013) reported that higher doses of azadirachtin mimicked the effects of chlorpyrifos on bacterial diversity. Both azadirachtin and chlorpyrifos showed a dose- and time-dependent effect, which was observable only at the RNA level. Endosulfan treatments showed dissimilar profiles compared to control. Most of the bands showed high sequence similarities to known bacterial groups, including many nitrogen-fixing, phosphate-solubilizing, and plant-growth-promoting bacteria. This study indicates that pesticides display non-target effects on active microbial populations that serve important ecosystem functions, thereby emphasizing the need to critically investigate and validate the use of bio-pesticides in agriculture before accepting them as safe alternatives to chemical pesticides.

Prabhat et al. (2014) studied the various concentrations of three commercial biopesticides: NeemBaan, Bactospeine (*Bacillus thuringiensis* (*Bt*) subsp. *kurstaki*) and Florbac (*Bt aizawai*), which they tested either in the field or laboratory or in both conditions. In the laboratory experiments, different concentrations of NeemBaan exhibited significant effects on the mortality of all the tested larval instars and a mortality rate of over 80% was recorded at a dose of 3000 ppm. Bactospeine was found to be more effective against *M. vitrata* than Florbac. Bactospeine applied at a lower dose of 500 ppm caused 100% mortality in the first-instar and second-instar larvae; however, at the same dose, Florbac caused mortality of only 26.67% (first instar) and 20% (second instar). In the field experiments, a higher dose of NeemBaan (6000 ppm) significantly reduced pod damage to approximately 20% in both the first and second cropping seasons. In conclusion, neem- and *Bt*-based biopesticide products have insecticidal potential to be used in an integrated pest management strategy for controlling *M. vitrata* in Thailand. Therefore, these studies have suggested that the use of biopesticides were found to be effective in minimizing the environmental pollution and to maintain the agricultural output.

In the recent studies, Senthil-Nathan (2015) reported that biopesticides, including entomopathogenic viruses, bacteria, fungi, nematodes, and plant secondary metabolites, are gaining increasing importance as they are alternatives to chemical pesticides and are a major component of many pest control programs. The virulence of various biopesticides such as nuclear polyhedrosis virus (NPV), bacteria, and plant product tested under laboratory conditions were very successful and the selected ones were also evaluated under field conditions with major success. Biopesticide products (including beneficial insects) are now available commercially for the control of pest and diseases. The overall aim of biopesticide research is to make these biopesticide products available at farm level at an affordable price, and this would become a possible tool in the integrated pest management strategy. Moreover, biopesticide research is still going on and further research is needed in many aspects including bioformulation and areas such as commercialization. There has been a substantial renewal of commercial interest in biopesticides as demonstrated by the considerable number of agreements between pesticide companies and bioproduct companies which allow the development of effective biopesticides in the market.

Moreover, Luca (2015) reported that bioinsecticides as environmentally friendly pest control tools to be integrated, in combination or rotation, with chemicals in pest management programs. In this scientific context, market data report a significant growth of the biopesticide segment. Acquisition of new technologies by multinational Ag-tech companies is the center of the present industrial environment. This trend is in line with the requirements of new regulations on integrated pest management. After a few decades of research on microbial pest management dominated by *Bacillus thuringiensis* (Bt), novel bacterial species with innovative modes of action are being discovered and developed into new products. Significant cases include the entomopathogenic nematode symbionts *Photorhabdus* spp. and *Xenorhabdus* spp., *Serratia* species, *Yersinia entomophaga*, *Pseudomonas entomophila*, and the recently discovered *Betaproteobacteria* species *Burkholderia* spp. and *Chromobacterium* spp. Lastly, *Actinobacteria* species like *Streptomyces* spp. and *Saccharopolyspora* spp. have gained high commercial interest for the production of a variety of metabolites acting as potent insecticides.

Additionally, Rai et al. (2015) reported that among the fungi isolated from adult insects, *Metarhizium anisopliae*, *Paecilomycetes, fumosorosens*, *Verticillium lecanii*, *Aspergillus flavus* and *Beauveria bassiana* proved to have pathogenic properties. The result of the experiment showed that different spray materials like Larvo Btk biopesticide, alone and in combination with Nimbokill at 0.7% level of concentration recorded 7% and 17% insect mortality, respectively. Thus, the literature clearly indicated that different biopesticides were found to be effective in controlling the various insects pest of agricultural crops.

CONCLUSION

The present review concluded that biopesticides are a set of tools whose applications will help farmers transit from highly toxic conventional chemical pesticides into an era of truly sustainable agriculture. Evidently biopesticides are only a part of a larger solution; sustainable agriculture is a broad and deep field. But helping farmers move from their current chemical dependency to organic agriculture and beyond requires tools for the transition and tools for a new era. Biopesticides can and will play a significant role in this process, in that they offer powerful tools to create a new generation of sustainable agriculture products. They are the most likely source of alternatives to some of the most problematic chemical pesticides currently in use that are under ever-increasing scrutiny. Biopesticides may also offer solutions to concerns such as pest resistance to traditional chemical pesticides, and public concern about side effects of pesticides on the surrounding environment and, ultimately, on human health. Thus, the application of different biopesticides was found effective to control the various pests of agriculture crops. Moreover the use of biopesticides will be promoted to sustain the yield of agricultural crops.

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