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MICROBIAL AND BOTANICAL: THE POTENTIAL SUBSTITUTES OF SYNTHETIC INSECTICIDES IN THE CONTROL OF AFRICAN RICE STEM BORER SPECIES

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ABSTRACT

Various stem borer species have been considered threats to rice production in Africa causing considerable yield losses depending on the type of stem borer species damaging the crop. The use of synthetic insecticides has been reported to be effective against stem borer problems but misuse and abuse make it unsuccessfully in the control of these stem borer species. Insect pest control has changed for a long time from using chemicals to natural control methods. Such natural methods include the use of microbial insecticides, *e.g.* Entomo-pathogenic fungi, Entomo-pathogenic bacteria, Entomo-pathogenic viruses, Entomopathogenic protozoa, and Entomo-pathogenic nematodes, and the use of botanical from different parts of plants, *e.g.* root, leave and seed extracts. This review introduces important issues on stem borer species, and the potential of different microbial pesticides and botanical extracts for the management of rice stem borers. These important issues that will be discussed include; different sources of microbial biopesticides and or /plant-based biopesticides (botanicals), their potential in the control of rice stem borers, and their mode of action. Microbial and plant-based biopesticides are important alternatives to synthetic insecticides due to their safety to the environment particularly human health and natural enemies.

Keywords: Stem borers, microbial pesticides, botanicals, insecticides, control

INTRODUCTION

Rice stem borers are among the most devastating insect pests of rice worldwide (Banwo et al. 2001; Sarwar 2012). There are three families of rice stem borers that contain the most damaging species. These include; Diopsidae family from the order Diptera: stalk eye fly, *Diopsis thoracica* Westwood; Pyralidae family from the order Lepidoptera: white stem borer, *Maliarpha separatella* Ragot, African yellow stem borer, *Scirpophaga* spp. and African striped stem borer and *Chilo* spp. and Noctunidae family from the order Lepidoptera: *Sesamia* spp. (Banwo et al. 2001; Leonard and Rwegasira 2015; January et al. 2020a). Rice stem borers have been reported to attack several cereal crops, causing significant losses depending on the crop. For example, yield losses of up to 80% have been reported for maize in Kenya (Ampofo 1986), 50% for sorghum in Ethiopia (Tefera 2004), and 54% for rice in Nigeria (Ukwungwu and Odebiyi 2008). Infestation of rice by stem borers starts right from the nursery to the reproductive stage of rice growth (Sarwar 2011; January et al. 2020b). When stem borers infested the rice crop, they caused different damage symptoms depending on the infested period of rice growth.

The larva is the only destructive stage where it finds suitable food to use until the end of the pupal stage when the pest protects itself from predators and adverse environmental conditions (Nwilene et al 2008). The older stem borer larvae feed within the stem and vascular tissues while the young larvae feed within the leaf sheath (Alinia et al. 2000). When infestation occurs during the vegetative stage (before panicle initiation), it results in the dead heart symptom while during the reproductive stage (after panicle initiation), it results in the development of the white head symptom (Pathak 1968; Dale 1994; Moche et al 2015).

The use of synthetic insecticides has been reported to be the most common technique to control stem borer problems (Prasad and Gupta 2012), but has been ineffective for several reasons, including environmental distraction, induced pest resistance, the high cost of insecticides, and the cryptic nature of stem borer attack (Ogah et al 2011; Prasad and Gupta 2012). Pest control has changed over the centuries from the use of chemicals to natural control methods (Shahid et al. 2012). Microbial-based insecticides (biopesticides) and plant-based insecticides (botanicals) are among the various natural control methods reported to be effective against insect pests of rice, especially stem borer, as an alternative to chemical pesticides (January et al. 2018).
The reported microbial biopesticides as natural insecticides against the stem borer problem include fungi such as *Beauveria bassiana* (Balls.) Vull and *Metarhizium anisopliae* (Metsch.) Sorokin (Tefera and Pingle 2008; January et al., 2018; bacteria *Bacillus thuringinensis* (BT) (Shahid et al. 2003); plant extracts such as *Azadirachta indica* L. (Islam et al. 2013), *Neorautanenia mitis* Verdic. and *Derris elliptica* Bench (January et al. 2018).

These natural insecticides have been reported to be effective not only against stem borers but also against other insect pests. For example, *M. anisopliae* and *B. bassiana* were reported to be effective against storage pests of maize (*Sitophilus zeamais*) (Teshome and Tefera 2009), *A. indica* and *N. mitis* against bean bruchid (*Zabrotes subfasciatus* Boh) (Mulungu et al. 2007), *D. elliptica* against melon fly in watermelon (Muro 2010), neem (*Azadirachta indica*), garlic (*Allium sativum*) and ginger (*Zingiber officinale*) against post-flowering insect pests of cowpea, *Megalurothrips* sjostedti and *Maruca vitrata* in Nigeria (Ogah, 2013).
These natural methods are considered to be environmentally friendly, preserve natural enemies, and delay insecticide-induced pest resistance (Ogah et al. 2011). This review highlights important microbial biopesticides: fungi *M. anisopliae*, *B. bassiana* and bacteria *B. thuringinensis* (Bt); nematodes: entomopathogenic nematodes; protozoa: *Nosema* spp. and *Vairimorpha necatrix*; Virus: baculovirus; Plants: *A. indica*, *D. elliptica*, *N. mitis* as sources of insecticidal activity against the stem borer problem, different sources of microbial biopesticides and/or plant based biopesticides (botanicals), their potential in rice stem borer control and their mode of action. Understanding these will assist researchers in designing IPM programs for rice stem borers.

Microbial insecticides

Several microbial pathogens are known to be used as bio-agents for controlling stem borers in various crops. These microbial pathogens comes from naturally occurring or genetically altered bacteria, fungi, viruses, nematodes, or protozoans (Katti 2013). Microbial pathogens can be effective and used as alternatives to chemical insecticides in managing insects that are injurious to plants (Mazid et al. 2011). The pathogenic effects of these microorganisms are highly species-specific. They infect the target pests by invading through the insect's integument or gut, leading to the pathogen's multiplication and ultimately the host's death. Studies have demonstrated that the pathogens produce insecticidal toxin important in pathogenesis (Katti 2013). Such identified toxins produced by microbial pathogens are called peptides and they vary in terms of structure, toxicity and specificity (Barges 1981). These micro-organisms are safe for human being and other non-target organisms as they leave less or no residue in food. They are also ecologically safe, such that they preserve other natural enemies and increase biodiversity in the ecosystem (Usta 2013). Such microbial include Entomopathogenic fungi: *M. anisopliae*, *B. bassiana*; Bacteria: *B. thuringinensis* (Bt); Nematodes: entomopathogenic nematodes; Protozoa: *Nosema* spp. and *Vairimorpha necatrix;* and Virus: Baculoviruses

Fungi based biopesticides

Entomopathogenic fungi are among the first organisms to be used for the biocontrol of agricultural pests (Hailu et al. 2012). They are host-specific with a very low risk of attacking non-target organisms or beneficial insects (Manisegaran et al. 2011). They have been reported to infect a very wide range of insects including lepidopterous larvae, aphids, and thrips, which are of great concern in agriculture worldwide (Roberts and Humber 1981). The fungi-based biopesticides are among

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environmentally friendly methods in combating stem borer problems. About 90 genera and 700 species of fungi representing a large group of entomopathogens (*Metarhizium* spp, *Beauveria* spp and *Verticillium* spp.) have been reported to be pathogenic (Manisegaran et al. 2011). Studies by Hailu et al. (2012) and Tefera (2004) in laboratory based experiments revealed many strains of *M. anisopliae* and *B. bassiana* isolates to have high level of mycosis against stem borers. Fukon et al. (2014) reported reduction in fruit damage by fruit borers (*Helicoverpa armigera* Hubner) by 89% and 87% as compared to control when tomatoes were sprayed with commercial *B. bassiana* and *M. anisopliae* respectively under field conditions in India. Further the study by Teshome and Tefera (2009) has revealed the potential of *B. bassiana* and *M. anisopliae* in control of storage pests of maize (*Sitophyllus zeamais* Mostch) in Kenya whereas January et al. (2018) reported *M. anisopliae* and *B. bassiana* to be effective against rice stem borers in both laboratory and screen house experiments.

Mode of action of Entomopathogenic fungi

The fungi affect the host as the insect cuticle comes in contact with the fungi during spray or larvae movement (Fig. 1). The fungi can then adhere to the host cuticle, germinate, form appressorium which penetrates the insect body, colonise the haemolymph, extrudes and sporulate which finally leads to the death of the host (Aw and Hue 2017).

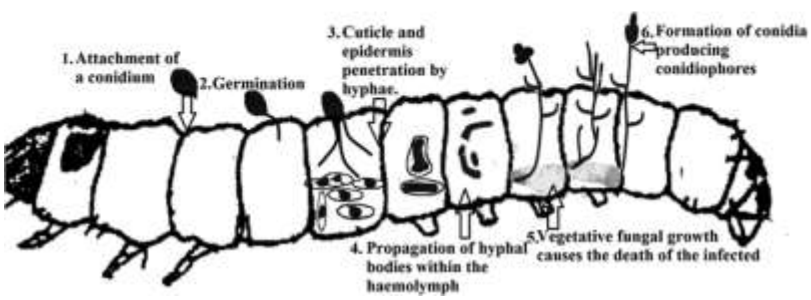

Fig. 1 Mode of action of entomopathogenic fungi against lepidopteran insects

Effects of Biopesticides on stem borer mortality/reduction of stem borer damages

The biopesticides including Fungi based biopesticides and botanicals are important remedies against stem borer problems. This can be revealed through the reduction of stem borer damage incidences when these biopesticides are sprayed on the rice infested by stem borers (January et al. 2018). Compared to other biopesticides, the fungi *M. anisopliae* and *B. bassiana*, have been reported to be more effective in the reduction of stem borer damage incidences (Table 1).

Table 1. Effects of biopesticides on reduction of dead heart and white head damages in rice crop

Treatment	Dosage	% < DHD ± SE	%<WHD ± SE
Amekan 344EC	0.25mil/L	-64.28 ± 2.36a	-76.19 ± 2.48b
Metarhizium anisopliae	1mil/L	-60.62 ± 2.44a	-70.70 ± 2.63b
Beauveria. bassiana	1mil/L	-61.86 ± 2.69a	-51.17 ± 3.44a
Neouratanenia mitis	10mil/L	-53.14 ± 3.34a	-49.28 ± 3.85a
Derris elliptica	10mil/L	-45.00 ± 4.22a	-42.01 ± 4.54a
Control (Untreated)		+100 ± 0.0b	+100 ± 0.0c
P-value		< 0.001	< 0.001
C.V		26.4	6

DHD = dead heart damage, WHD = White head damage, SE= standard error and C. V = Coeffient of variation.

% Reduction / increase of DHD or WHD were calculated using the Control mean data of Dead heart or White Head as 100% incidence. Negative sign (-) indicate % of reduction while positive sign (+) indicate % of increase in dead heart or white head. Data were arcsine transformed prior to analysis. Presented data are original values.Means followed by the same letters are not significantly different ($P > 0.05$) using Student Newman Keuls (SNK)
(**Source:** January eta al. 2018)

Entomopathogenic Bacteria

Various bacterial species and subspecies, especially *Bacillus*, *Pseudomonas*, etc., have been established as biopesticides and are primarily used to control insect and plant diseases (Senthil-Nathan 2015). Notably, several subspecies of Bacillus thuringiensis Berliner are prominent among these insecticides. These include B. thuringiensis ssp. kurstaki and aizawai, which are highly effective against lepidopteran larvae; B. thuringiensis israelensis, which targets mosquito larvae, black flies (Diptera: Simuliidae), and fungus gnats; B. thuringiensis tenebrionis, which is effective against coleopteran adults and larvae, including the Colorado potato beetle (Leptinotarsa decemlineata); and B. thuringiensis japonensis strain Buibui, which targets soil-dwelling beetles (Carlton 1993 ; Copping and Menn 2000).

Mode of action of entomopathogenic bacteria in the control of stem borers

The mode of action of most Entomopathogenic bacteria including *B. thuringiensis* is the production of a crystalline proteins that kill few target insect pest species like lepidopteran species. The binding of the Bt crystalline proteins to insect gut receptors determines the target insect pest (Kumar 2012). Toxicity of *B. thuringiensis* and some other toxic strains is commonly imputed to the parasporal inclusion bodies (δ-endotoxins) which are produced during sporulation time. For these endotoxins to be effective, they must be ingested by the larvae. This is the case with Bacillus thuringiensis and its subspecies. produce different insecticidal crystal proteins (δ-endotoxins), and their toxicity was determined (Chilcott et al. 1983; Aronson and Shai 2001). When ingested by larvae, these toxins can damage gut tissues, causing gut paralysis. Consequently, the infected larvae cease feeding and eventually die from a combination of starvation and damage to the midgut epithelium. (Fig. 2) (Betz et al. 2000; Darboux et al. 2001).

Entomopathogenic nematodes

The commonly known entomopathogenic nematodes are from two genera, namely, *Steinernema* and *Heterorhabditis* (Nematoda: Rhabditida), which were discovered in the 1990's and established as a biocontrol agent against insects (Copping and Menn 2000). Most studies of nematodes attacking stem borers have been reported in Africa (Otieno 1986). Various efforts have been used in controlling insect populations in the field by employing infective Juvenile stages of entomopathogenic nematodes (Peter 1996).

Mode of action of entomopathogenic nematodes

Insect-parasitic nematodes may encroach upon soil-dwelling stages of insects and kill them within 48 hours through the expulsion of pathogenic bacteria. After the host dies, the infectious stages of the nematodes become adults and a modern generation of infective juveniles (IJs) develops (Fig. 3). In nematodes, the parasitic cycle begins with third-stage infective juveniles (IJs). These nonfeeding larvae invade suitable insect hosts through natural body openings such as the anus, mouth, and spiracles (Grewal et al. 1997). Once inside the host, nematodes invade the hemocoel and then release their symbiotic bacteria into the intestine. The bacteria induce septicemia, resulting in the host's death within 24 to 48 hours (Fig. 3). The bacteria quickly take control of the IJs, leading to the decomposition of the host tissues. Almost two to three generations of the nematodes are finished within the host cadaver (Bird and Akhurst 1983).

Protozoa

Nearly 1,000 protozoan species, primarily microsporidia, infect invertebrates, including many insect species such as grasshoppers and heliothine moths. Notably, Nosema spp. are among the most well-known protozoan pathogens ofinsects and *Vairimorpha necatrix*. *Nosema partelli* Walters & Kfir,is endemic to South Africa

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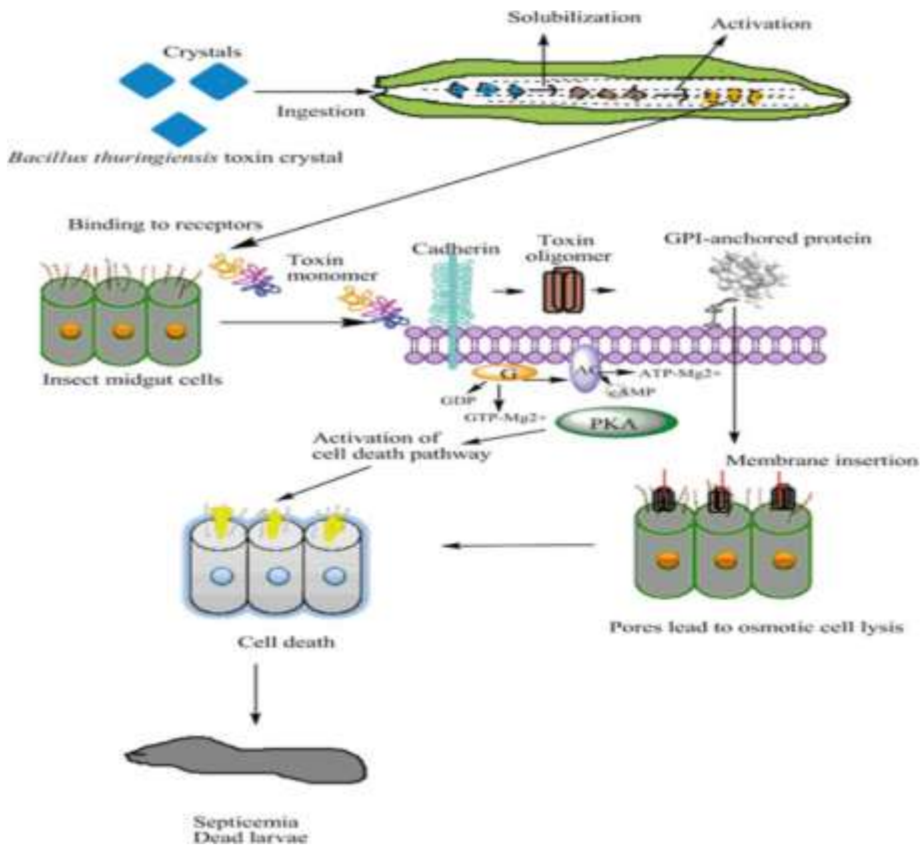

Figure 2: Mode of action of *Bt* toxin against lepidopteran insects (Senthil-Nathan 2015)

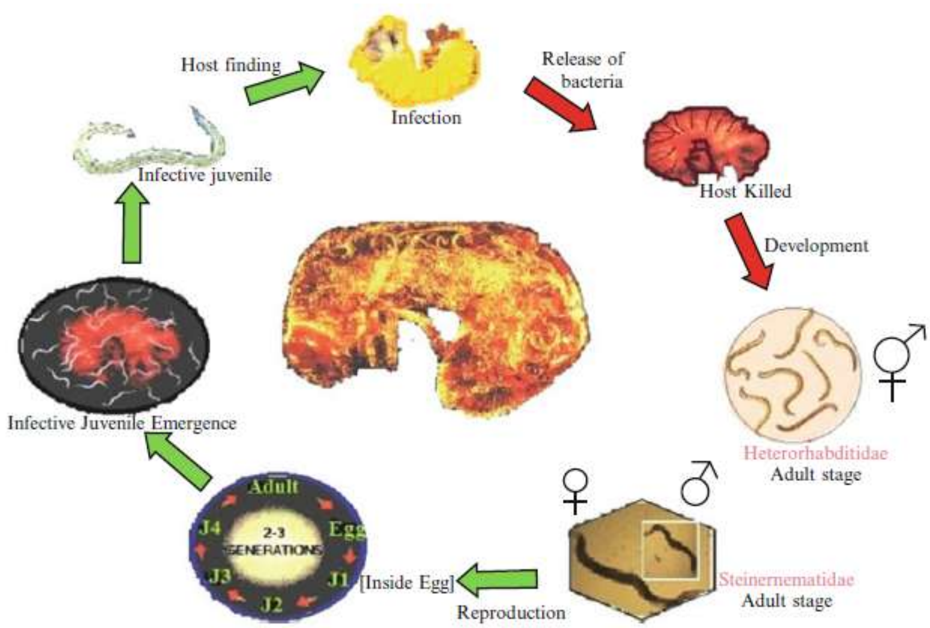

Fig. 3 Mode of action of entomopathogenic nematodes against lepidopteran insects (Senthil-Nathan, 2015)

and is a widespread disease in field and laboratory populations of *C. partellus* in the region (Walters & Kfir 1993). However, it was only infective in laboratory cultures and less active under field conditions. *Nosema* sp., has great potential as both a cheap and effective control agent in Kenya (Odindo et al. 1993).

Mode of action of protozoa

Protozoans produce spores, which are the infectious phase in several susceptible insects. *Nosema* spp. spores are assimilated by the host and develop in the midgut. Germinating spores are released from the sporoplasm and invade the host's target cells, leading to widespread infection and destruction of organs and tissues. The sporulation process then resumes in the infected tissues, and when these spores are expelled and ingested by a new susceptible host, they trigger an epizootic infection.Naturally, parasitoids and insect predators commonly act as vectors distributing the disease (Brooks 1988).

Viruses

Over 1,600 distinct viruses infect 1,100 species of insects and mites. A special group of viruses, called baculovirus, to which about 100 insect species are susceptible, accounts for more than 10 percent of all insect pathogenic viruses. Baculoviruses are rod-shaped particles that contain DNA (Usta, 2013). These are double-stranded DNA viruses found primarily in arthropods, especially insects. Baculoviruses are typically highly pathogenic and have been effectively used as biocontrol agents against a wide range of significant insect pests (Moscardi 1999). In the Lepidoptera, the main group from which baculoviruses are isolated, they cause mortality exclusively in the larval stage (Cory 2000).. Studies made in Kenya and South Africa identified granulosis viruses, polyhedral inclusion bodies, cytoplasmic polyhedrosis virus and entomopox virus (Odindo et al. 1989; Hoekstra & Kfir 1997). In Egypt, infection by nuclear polyhedrosis virus of *Chilo agamemnon* Bleszynski (Lepidoptera: Crambidae) (Abbas 1987), had a detrimental effect on the development of a larval parasitoid, *Habrobracon brevicornis* Wesmael (Hymenoptera: Braconidae). In India, granulosis viruses have been used with some success for the control of *Chilo sacchariphagus* Stramineelus (Caradza) (Lepidoptera: Pyralidae) and *Chilo infuscatellus* Snellen (Lepidoptera: Pyralidae) (David & Easwaramoorthy, 1990).

Mode of action of virus/baculoviruses

Baculoviruses must be consumed by larvae to start an infection. Once ingested, they enter the insect's body via the midgut and then spread throughout, although in some insects, the infection may be restricted to the midgut or the fat body. (Fig. 4). Baculoviruses are divided into two categories: nucleopolyhedroviruses (NPVs) and granuloviruses (GVs). NPVs feature occlusion bodies filled with many virus particles, while GVs generally have occlusion bodies containing a single virus particle. A defining trait of baculoviruses is their occluded state, where virus particles are embedded in a protein matrix. This occlusion is vital for baculovirus biology as it allows the virus to remain viable outside the host (Cory 2000). Similarly, most viruses are surrounded by a protein coat, creating a virus inclusion bodyAlkaline condition of insect's midgut dissolves the protein covering and the viral particles are released from the inclusion body. These particles fuse with the midgut epithelial cells, multiply rapidly and eventually kill the host (Usta 2013).

Botanical insecticides

Botanical insecticides are synthetic derivatives of the naturally occurring secondary metabolites synthesised by plants species, which act on the insect growth and survival. They have long been advertised as attractive substitutes to synthetic chemical-insecticides, for controlling many insect pests because botanicals reputedly pose little threat to the environment or to the human health (Katti 2013). There are several reports on the utilization of botanicals against insect pests. The effectiveness of botanical insecticides has been well established in managing insects and they have been recommended for use by farmers with limited resources. (Mulungu et al. 2011). Mulungu *et al*. (2007) reported a significant reduction in beans damage by bean bruchid (*Zabrotes subfasciatus* Boheman) when common beans (*Phaseolus vulgaris* L.) were treated with Nyongwe (*Neorautanenia mitis* Verdic), Pyrethrum grist (*Chrysenthemum cinerariaefoliun* Boccone) and garlic (*Allium sativum* L.*)* extracts before storage.

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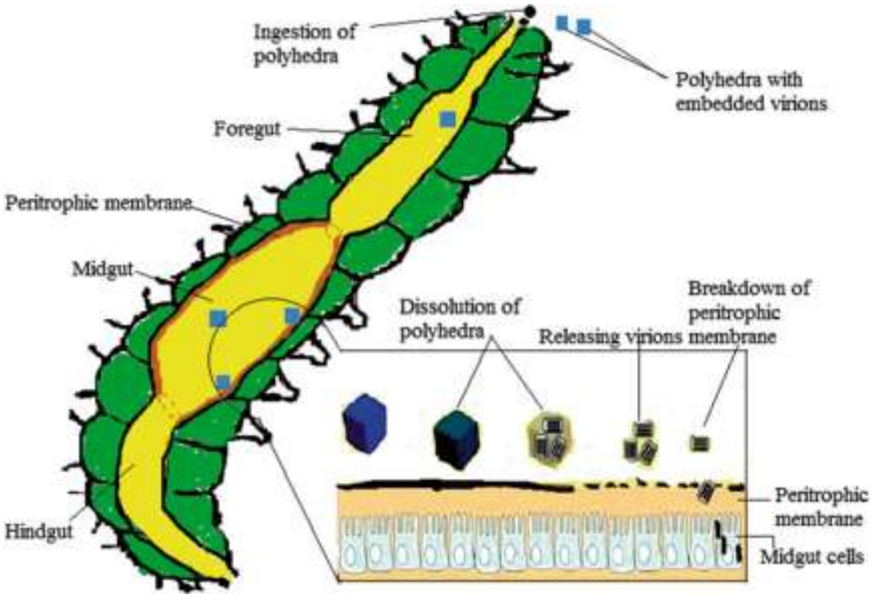

Fig. 4 Mode of action of baculoviruses against lepidopteran insects (Senthil-Nathan, 2015)

Visetson and Milne (2001) reported highly toxic effects of rotenone extracts from Derris plant (*Derris elliptica* Bench) on larva of Diamond back moth (*Plutella xylostella* Linn) in Chinese kale. Further studies by Sangmaneed *et al*. (2005) revealed high mortality of pig fly (*Faria canicularis* L. larvae when treated with fresh and dry *D. elliptica* powder. Muro (2010) reported high mortality of melon fly (*Bactocera cucurbitae* Conquillet) using *D. ellitica* bites in water melon. Importantly, this is that which has been reported by January et al. (2018) against rice stem borers (Table 1). The use of botanicals as pest control methods have been formulated in response to public awareness of environmental and health impacts of synthetic pesticides and resulting legislation. In this process, standardization of active principles of botanical products and their contents was done by suitably formulating them as biopesticides for reliable, better and consistent results. It was also developed as key component of integrated pest management (IPM) programs, mainly as a means to reduce sole biopesticidal treatments in controlling insect pest infestation and increasing rice grain yield over control (Rao and Singh 2003; Rao et al. 2006).

CONCLUSION

The bio-intensive approach to pest management is an ecologically based strategy that aims to provide a long-term solution for pest control through a combination of techniques. These include the use of resistant varieties, biological control, modification of agronomic practices, and habitat manipulation. The use of bio-pesticides, mainly microbial insecticides and botanical products, is an integral component of this approach, as it allows for the minimisation of risks to human health, beneficial and non-target organisms, and the environment.

The development, manufacture, and utilisation of botanical pesticides face several constraints. These include a lack of multidisciplinary research, inadequate public-private partnerships and a poor understanding of their quality aspects. Generally, farmers are accustomed to the quick knock-down effects of pesticides. Therefore, they may not be satisfied with the slower action of biopesticides. Consequently, there is a necessity to educate farmers about the distinctive behavioural effects of these products and to create awareness among extension specialists and policy makers regarding the potential utilisation of biopesticides. Further, more concentrated research efforts in the areas of production, formulation and development of effective delivery systems are required to effectively harness their potential and to convince farmers of their role as equally efficient and eco-friendly alternatives to conventional chemical pesticides.

Microbial insecticides are generally safe and do not harm wildlife, humans, or other organisms that are not closely related to the target pest. Microbial insecticides typically target a specific group or species of insects, which means they usually do not harm beneficial insects, such as predators or parasites of pests, in the treated areas. Conversely, this specificity may result in the survival and continued damage caused by other types of pests in the treated area. The effectiveness of several types of microbial insecticides is reduced by heat, desiccation (drying out), or exposure to ultraviolet radiation. Therefore, it is of particular importance to adhere to the correct timing and application procedures for certain products. Specialised formulation and storage procedures are necessary for some microbial pesticides.

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