Review Article

Bioefficacy of insecticidal nematodes against stored grain pests-an overview

Abstract: Stored grain insect pests are difficult to control. Though chemical insecticides are effective in controlling pests, other environment friendly methods have been advocated. Entomopathogenic nematodes are potential biocontrol agent against a wide range of insect pests. This review highlights the research findings regarding the use of entomopathogenic nematodes against stored grain insects.

Key words: Stored grain pests, biological control agent, entomopathogenic nematodes (EPNs), bioefficacy.

Introduction

The insect pests attack and destroy large quantities of stored grains and products during postharvest processing and storage in farm bins, grain processing facilities, warehouses, retail stores, and eventually also on the consumer shelves. Stored grain / product pests are generally difficult to control using traditional method as they hide in cracks and crevices, under perforated floors, and inside machinery used for processing of stored products. Thus they have a major economic impact on the food industry due to the costs associated with their management, monitoring, rejection, and return of contaminated shipments and failure to meet regulations that required to and pass inspections. Therefore, there is a need to protect stored food products from attack by insects.

Important stored grain pests

The Indian meal moth (*Plodia interpunctella*), the larval stages feed on different kinds of cereal grains and processed dry foods.

The Mediterranean flour moth (*Ephestia kuehniella*), the larval stage feed on various types of flour.

The Mealworm (*Tenebrio molitor*), larvae feed on flour of cereals.

The kharpa beetle (*Trogoderma granarium*) and the warehouse beetle (*Trogoderma variabile*), larvae feed on dried cereal grains, dried spices and food products. These are destructive stored product pest due to their elevated survival potential, preference for dry conditions and resistance to many insecticides.

The red flour beetle (*Tribolium castaneum*) feeds on cereal grains and dried food products. The confused flour beetle (*T.confusum*) is another pest that contaminates a wide range of food products, from cereals to spices.

The granary weevil (*Sitophilus granarius*) and the sawtoothed grain beetle (*Oryzaephilus surinamensis*) are important pests of stored grain of wheat and barley and other cereal products, spread mostly in moderate climate .

The lesser grain borer (*Rhyzopertha dominica*) is a destructive, internal grain feeder of stored cereals throughout the world.

Synthetic pesticides, especially fumigants, have achieved sufficient pest control at low cost for stored grain pests. As the public concern about chemical pesticide related risks increases, the development of alternative, environmentally more caring disinfestations methods of stored commodities should be pursued. Other techniques such as the use of extreme temperatures and the use of biological control agents are also utilized effectively. However, any organism has been considered as an undesirable contaminant of stored product, limited the applicability of biological control measure.

Entomopathogenic nematodes (EPNs)

Laboratory experiments showed that entomopathogenic nematodes (EPNs) are the potential biological agents for suppressing some species of stored products pests. The free living third-stage infective juveniles (IJs) of the entomopathogenic nematodes such as *Steinernema* and *Heterorhabditis* under the families Steinernematidae and Heterorhabditidae respectively, get into their hosts body through mouth, anus and spiracles and release symbiotic mutualistic bacteria into the hemocoel causing septicemia or toxemia and finally the death of the insect within a few days . Generally, for beetle species, entomopathogenic nematodes are considered more effective against the larval stage, in comparison with adults (Kakouli-Duarte *et al*., 1997, Ramos-Rodroguez *et al*., 2006, Athanassiou *et al*., 2008). Most of the adults are more mobile and may partially avoid the contact with entomopathogenic nematodes. The successful application of entomopathogenic nematodes in storage environments for controlling post-harvest insects is highly dependent on several biotic and abiotic factors, such as the host life stage, temperature, and relative humidity. It is known that the grains and the storage environment are dry and application of entomopathogenic nematodes to dry storage environment is risky. Entomopathogenic nematodes have to overcome this problem to become a reliable alternative for commercial applications in warehouses and storage facilities.

Utilization of entomopathogenic nematodes against stored grain pests

Entomopathogenic nematodes (EPNs) have been used against different species of stored grain insects. Entomopathogenic nematodes (EPN) species differ in their capability to withstand rapid desiccation (RD). Infective juveniles of *S. carpocapsae* are a better adaptable and tolerant than *S.*

feltiae or *H. bacteriophora* as, an optimal RH of > 90% is required by *S.feltiae* and *H. bacteriophora* while maintaining RH equivalent to 74% could sustain survival of *S.carpocapsae* under RD (Ramakrishnan *et al*., 2022). Understanding the rate of desiccation among IJs of different EPN species, at range of relative humidity (RH) conditions, as well as the influence of these conditions on nematodes efficacy against those pests will enable to develop formulations to enhance EPN survival and efficacy.

Alikhan *et al*., (1985) showed that *S. feltiae* was moderately effective against the granary weevil (*Sitophilus granarius*) and caused low mortality to *T. confusum* larvae.Cruiser entomopathogenic nematode, *H.bacteriophora* and *H.megidis* are more virulent against adults of Indian meal moth (*Plodia interpunctella*) than against larvae (Mbata & Shapiro-Ilan 2005). Intermediate foraging entomopathogenic nematodes *S.riobrave* have a potential to kill over 65% larvae of Indian meal moths, Mediterranean flour moths, sawtoothed grain beetles, mealworms, red flour beetles and warehouse beetles. Intermediate foraging entomopathogenic nematode *S.feltiae* can cause over 90% larval mortality of Indian meal moth, Mediterranean flour moth, red flour beetles (Ramos-Rodriguez *et al*., 2006). However, they found that S. *carpocapsae* was more effective than *S. feltiae* for killing of larvae of *E. kuehniella.* Ramos-Rodroguez *et al*., (2006) found that entomopathogenic nematodes were generally more effective against larvae of the red flour beetle, *Tribolium castaneum* than against adults. Trdan *et al.*, (2006) noted that high doses of *S. carpocapsae* were required to achieve a high level of mortality against the sawtoothed grain beetle (*Oryzaephilus surinamensis*). *S. feltiae* was more effective against *S. granaries* and *O. surinamensis* at 20 and 25°C than at 15°C. Athanassiou *et al*., (2008) found that virulence of *S. feltiae* varied considerably among different strains, against adults and larvae of *T. confusum* and larvae of *E. kuehniella*. Intermediate foraging entomopathogenic nematode *S.feltiae* can cause over 79% larval mortality of the flour beetle. Furthermore, in that study, the most effective strain against *T. confusum* larvae was not effective against *E. kuehniella* larvae. *E. kuehniella* larvae wheat treatments with *S. feltiae* provided mortality that ranged from 36.7 to 78.3% where as no mortality was noted in the treatment with *S. carpocapsae* at 100 IJs per ml at 20 or at 30°C. Also, at 20°C, in wheat treated with *H. bacteriophora* at 100 IJs per ml, very few larvae were dead. *R. dominica* adults, at 20°C, the mortality of adults in wheat treated with *S. feltiae* and *S. carpocapsae* did not exceed 23.3 and 41.7%, respectively, at 20,000 IJs per ml, with no significant differences among doses. In the case of *S. oryzae* adults, the mortality was very low at all doses, and temperatures and did not exceed 9%. Mortality of *T. confusum* adults did not exceed 17% regardless of the entomopathogenic nematode species tested. In contrast, mortality of *T. confusum* larvae was notably higher and exceeded 56% in wheat treated with 10,000 or 20,000 IJs per ml of *S. feltiae* at 20°C. Unlike *S. feltiae* and *S. carpocapsae*, the application of *H. bacteriophora* resulted in lower mortality levels (Athanassiou et al.,2010). Mortality rates of adult specimen of rice weevil (*S.oryzae*) depend on temperature and concentrations of nematode suspension (*S. feltiae* B30, B49 and 3162), as well as on the strain of nematodes (Laznik *et al*., 2010). *S.feltiae*, *S.carpocapsae* and *H.bacteriophora* killed 87.8, 63.3, and 60.0% respectively of the exposed large larvae (*T. granarium*) on stored wheat treated with 50000 IJs/ml after 8 days of exposure at 30°C under laboratory condition (Karanastasi *et al*., 2020). The concentration of 150 IJs/beetle *Tribolium confusum* and *Rhyzopertha dominica* achieved a maximum mortality of 100% for *S. pakistanense* at 30°C. The same concentrations revealed that all four species of EPN were able to cause mortal effects depended on temperature and concentrations. *S. pakistanense* (LM-07) and *S. bifurcatum* (LM-30) were the most effective at 150 IJs/beetle at 30°C and *S. affinae* (GB-14) and *S. cholashanense* (GB-22) at the same concentration at 20°C (Javed *et* *al*.,2020). *Steinernema riobrave, Heterorhabditis bacteriophora* showed various levels of efficacy against Cowpea weevil (*Callosobruchus maculates*), Khapra beetle (*Trogoderma granarium*), and Rust red flour beetle (*Tribolium castaneum*).The highest mortality rate 16.67% was recorded with *S.riobrave* (2000 IJs / ml) after 72 hours post-treatment of *C. Maculates*, while the lowest rate of mortality (1.33%) of adult insects for rusty flour beetle at the dose of 500 IJs / ml after 24 hours (Qader *et al*., 2021).

Conclusion

A thorough knowledge of the biology and technology of the stored product and above all of the pests, their physiology and behavior and their natural enemies is essential for management of these pests. Improved design of factories, granaries, and warehouses to avoid insect infestation and facilitate control operations at an early stage in the planning of a new building. Environmental conditions in these buildings are very important along with good sanitary measures and sophisticated monitoring techniques in order to render the conditions unfavourable for development of the insects (Scholler *et al*., 1997). To establish a treatment threshold, direct sampling, location of insect infestation, the insect species present, and their developmental stage. Since stored product environments are enclosed, biological control options are restricted to augmentative biological control. For large scale application, products for control have to be ready to use and easy to apply by means of simple equipment. Also, the provision of an aqueous environment in the insecticide formulation of the entomopathogenic nematode is required so that the nematode can reach the target. The virulence of entomopathogenic nematodes against post harvest insects varies depending on the nematode species and strains. Usually, only a single nematode species or strain is not equally effective against all major stored product insect pests, therefore, one nematode species or strain cannot be suitable for controlling all species present in the storage environment, where several insect species coexist. With the discovery of new, virulent strains, evaluation of heat-tolerant strains, use of innovative, enhanced methods of formulation and application, such as encapsulation or bait traps, could boost the exploitation of entomopathogenic nematode in storage facilities against post-harvest insects.

Additional investigation is needed to clarify the level of consumer's acceptance on pathogen-treated (biocontrol agent) food, because the use of pathogens directly in food may not be compatible with the consumer's demands (Athanassiou *et al.*, 2008).

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