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Entomopathogenic nematodes: A sustainable biocontrol agent against insect pests

Umer Liaqat[1,2+], Muhammad Arshad[1*], Muhammad Asad[1], Soban Asif[1] and Sundus Akram[2]

1. Insect biodiversity and biosystematics laboratory, Department of Entomology, University of Agriculture, Faisalabad.
2. Department of Zoology, Wildlife and Fisheries, University of Agriculture, Faisalabad

*Corresponding Author: **drarshaduaf@uaf.edu.pk**
+Corresponding Author: **Umer.liaqat@uaf.edu.pk**

ABSTRACT

Lepidopterous insect pests poses a serious threat to global agriculture. Increasing insecticides resistance in insects and environmental hazards have encouraged researchers to explore more sustainable approaches. This study highlights the potential of entomopathogenic nematodes (EPNs) sustainable biological control agents against agricultural pests. They are obligatory insect parasites in soil. EPNs are soil-dwelling insect parasites that locate hosts through chemical cues and enter via natural openings (mouth, anus and spiracles). Once inside, they release mutualistic bacteria that kill the host within 24-72 hours, allowing the EPNs to feed, mature and reproduce for one to three generation. EPNs offer several advantages and compatibility with new chemistry insecticides, making them valuable component of pest management programs. However, factors like temperature, humidity, ultraviolet radiation, shelf life and production cost can limit their use. This article highlights the importance of entomopathogenic nematodes, biology, application techniques and efficacy, while highlighting key limitations and research gaps. The study highlighted optimizing time and application methods and native strain selection can enhance performance.

Keywords: Entomopathogenic nematodes (EPNs), insect pests, Lepidopterous, sustainability, Integrated pest management

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Introduction

The agricultural insect pest's management is a censorious challenge throughout the world for food security. The insect pest related to order lepidoptera causes severe damage to a wide variety of crops. Previously, insect pest management strategies mostly relied on synthetic insecticides and chemicals. While the use of insecticides and pesticides to control these insect pests link to various issues, like development of resistance against insecticides, pest resurgence, non-targeting impacts and environmental hazards [1-3]. These concerns push the researcher to think about alternative, eco-friendly and sustainable control methods. Among these the most favorable alternatives are the use of microbial control agents and microbial insecticides/ pesticides, which employ living organisms and their byproducts as an active ingredient to with target specific abilities [1].

The EPNs are a particular microbial control agents in soil ecosystem against lepidoptera's. These microbial agents have dual characteristics to act as both natural enemies and pathogenic microorganisms [1]. These microbes are obligatory parasites of insects [2, 4]. These microbes successfully control the stem borers that are obtuse to manage with conventional and synthetic insecticides [5]. Several studies prove their effectiveness against large numbers of insect pests like weevils, grubs and various lepidoptera like fall armyworm [6]. This study provides a short review on biology of EPNs, their advantages and disadvantages as biocontrol agents, and the key facts regarding their use or effective application for sustainable agriculture.

2. Biology and efficacy of entomopathogenic nematodes

2.1 What are Entomopathogenic nematodes?

These are the lethal parasites of insects, related to two families Heterorhabditidae and Steinernematidae [3, 7]. The entomopathogenic nematodes (EPNs) have a mutualistic symbiotic association with specific type of bacterial genus (the genus heterrorhabditis has mutualistic relation with bacterial genus *Photorhabdus* and steinernematids with genus *Xenorhabdus*) [8, 9]. This combination forms a functional unit which is responsible for the sever pathogenicity against insect pests [8, 10]. The EPNs have several life stages, but 3rd stage is more crucial for pest management, known as infective juveniles (IJs) stage [11]. The other EPNs stages are non-feeding and free-living that can survive without host for two to several months. The physiology and morphology of EPNs allow them to adapt and seek new hosts. Moreover, EPNs are cosmopolitan in distribution (lived throughout the world except Antarctica), lived in soil ecosystems and can collectively infect many insects, making them ubiquitous natural enemies in several agroecosystems [12]. In Pakistan, survey studies proposed that several species of EPNs have identified such as Steinernema pakistanense, S. asiaticum, S. abbasi, S. balochiense, S. siamkayai, Heterorhabditis Indica and H. bacteriophora, which are present in soil ecosystem of Pakistan [13-15].

2.2 Mode of action of EPNs and Life cycle

The mode of action begins when the infective juveniles actively seek the host larvae, by using cues like chemical cues [12]. Once appropriate host is located, the infective juveniles (IJs) reached and penetrates the insect body through natural openings (mouth, anus and spiracles), studies reported that some species of EPNs can penetrate the larval body directly through cuticle [2, 11].

After entering the IJs moved to hemocoel of the insect's body and releases mutualistic bacteria [16], the bacteria's start multiplication inside the insect host and starts tissue breakdown, which killed the insect host within 24 to 72 hours due to septicemia [17, 18]. These bacteria also generate wide types of toxins and antimicrobial substances that help to protect insect larval cadaver from being colonized by other competing microorganisms (Fig. 1) [8, 12]. Then IJs of EPNs feed on the host digested tissues and multiplying bacteria, maturing into adults and reproducing. One to three generations of EPNs can develop inside the protective environment of insect cadaver. After depletion of host's resources, the new generation of IJs emerges from the cadaver, dispersing into soil to locate new hosts and continue the life cycle [11, 16].

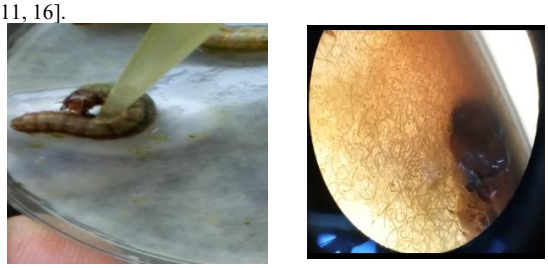

Figure 1: Emergence of Entomopathogenic nematodes from fall armyworm cadaver in insect biodiversity and biosystematics laboratory, Department of Entomology, University of Agriculture, Faisalabad.

3. Advantages of Entomopathogenic nematodes in pest management

EPNs have several characteristics that make them highly suitable candidate for use in sustainable and integrated pest management approaches.

3.1 Safety and environmental compatibility

The safety profile of EPNs is one of the most significant features of EPNs. They are harmless to plants, vertebrates and most non-target arthropods, so, they are posing No and negligible impact on environment [1, 18]. This strong specificity enables them to control pest species without harming beneficial insects like pollinators and natural predators. Their proven safety has led the U.S. Environmental Protection Agency (EPA) to exempt EPNs from pesticides registration requirements [16, 19].

3.2 Large host range and high virulence.

EPNs have broad host ranges and single species of EPN is capable of infesting hundreds of various types of insects collectively [12], which make them useful tools for controlling variety of insect pests in horticulture and agroecosystem [6].

3.3 Application and integration

The EPNs can apply using standard application methods like spray equipment, i.e. hand sprayers and soil drenching through irrigation. EPNs can also be used in integration with various types of conventional insecticides, herbicides and fertilizers [17]. In some instances, EPNs showed synergistic interactions, when used alongside, with some specific chemical insecticides, for example neonicotinoids, leading to maximum pest control [19].

3.4 Active seeking host

Unlike chemical insecticides that need to come into contact with pests, EPNs are living things capable of seeking hosts actively [5, 6]. This is especially beneficial for managing the hidden pests that live in the soil, inside plant stems and in other protected spaces where contact insecticides are less effective [17], so, EPNs do not require the precise coverage that chemical sprays do.

4. Challenges and limitations

Although they have significant potential, the large-scale adoption and commercialization of EPNs are limited by several key challenges.

4.1 Environmental sensitivity

The environmental conditions had significant impact on efficiency of EPNs. As an aquatic organism, entomopathogenic nematodes need a thin film of moisture to move forward and avoid desiccation [17]. This limits their effectiveness in extremely dry conditions. Additionally, they are sensitive to ultraviolet radiation (UV), it rapidly killed and lower the pathogenicity of EPNs [10]. Another important factor is that each EPN species has a specific optimal range for infection and reproduction, and their performance declines when conditions fall outside this range [9].

4.2 Shelf-life and storage

As living things, EPNs have a shorter life span than chemical insecticides. The commercial formulation of EPNs mostly requires refrigerator for storage and maintain infectivity, even then EPNs have short life span [19]. However, various types of novel formulation have been tested and produced in future.

4.3 Production costs

Mass production of EPNs is laborious and requires technical expertise, weather in vivo using insect hosts or in vitro through bioreactor [20]. The combination of both high production cost and a limited marker share can result in EPN products being more costly for end users than traditional chemical insecticides [19].

5. Future prospective

The widespread adoption of EPNs as a mainstream biocontrol agent requires to address the current limitations through ongoing research and development.

5.1 Advances in formulation technologies

Advancement in formulation technology is essential to enhance the field efficacy and shelf-life of EPNs. Research to overcome anhydrobiosis limitation of EPNS with the long shelf-life and to create non-refrigerated formulations [16]. For example, some research innovations include gel formulation, gum kateria formulation or polymer coatings and other inert materials [7].

5.2 Genetic improvements and selection of strains

Future research should focus on genetic improvements in entomopathogenic nematodes (EPNs). Approaches like hybridization, selective breeding and genetic engineering could yield stain with greater environmental tolerance, better storage stability, strongest host seeking abilities and higher virulence against key pests related to order Lepidoptera [19]. The discovery of indigenous EPN strain already adopted to local environmental conditions constitute an additional promising avenue for research [9].

5.3 Integrated pest management

EPNs functions most effectively as component of an integrated pest management strategy (IPM), rather than as independent control agents. EPNs are also compatible with various types of insecticides [2]. Investigating and utilizing the synergistic effect between EPNs and specific low toxicity chemical insecticides may enhance both the efficacy and economic feasibility of pest management strategies [19]. They are also compatible with various types of biocontrol agents like Entomopathogenic fungi and bacteria.

6. Conclusion

In conclusion, the entomopathogenic nematodes exhibited great potential against insect pests and considered a sustainable tool for the management of agricultural pests. Their exclusive mode of action, environmental safety and compatibility with different agricultural practices make them an attractive alternative to synthetic insecticides/ pesticides. Although some challenges in environmental sensitivity can hinder the adoption of EPNs, nonetheless, novel formulations technologies and genetic engineering may hold great promise. The careful selection of native strains of EPNs, optimizing time and application methods and their integration with broad IPM frameworks, make EPNs a key contributor to managing insect pest more resiliently for sustainable agriculture.

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