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Innovative Strategies in Insect Pest Management

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Agricultural production and productivity are constrained by both biotic and abiotic factors, with insects being one of the major biotic challenges. Thus, pest management is an important aspect of sustained agricultural production. For decades, the traditional pest management practices have mainly relied on chemical pesticides. Further, pesticide residues cause serious health hazards and ill effects on the environment and non-target organisms. Hence alternative management strategies need to be adopted to overcome the present obstacles that are sustainable, efficient and environmentally friendly.

Introduction

The widespread use of hazardous pesticides has led to issues such as insect resistance, resurgence, and secondary outbreaks. To address these problems, various alternative pest management methods have been developed, including biological control, cultural practices, mechanical controls, behavioural strategies, and recent advances in genetic and biotechnological approaches. These alternatives seek to minimize dependence on chemical pesticides and promote a more balanced and sustainable approach to pest management. A few of alternative management practices are discussed below:

1. **Use of biological control agents:** Over the past three to four decades, the use of biological control agents has significantly increased due to their high efficiency, specificity, and environmental sustainability. A wide variety of living organisms can serve as biocontrol agents. Predators of insect pests typically include insects, spiders, and mites, with over 40 families of insect predators identified. Approximately 75% of parasitoids belong to the order Hymenoptera, with the remaining species primarily from Diptera and Strepsiptera. Pathogens that target insect pests include bacteria, fungi, viruses, and nematodes. Among entomopathogenic bacteria, Bacillus thuringiensis subspecies—such as *B. thuringiensis* subsp. *israelensis*, *B. thuringiensis* subsp. *aizawal*, and *B. thuringiensis* subsp. *tenebrionis*—have proven effective in controlling various insect species. Entomopathogenic viruses, particularly nuclear polyhedrosis viruses (NPVs) and granulosis viruses (GVs), have been isolated from thousands of insect species and are effective against pests across multiple orders. A diverse range of entomopathogenic fungi also targets insect pests, with *Beauveria bassiana and Metarhizium anisopliae* being the most commonly used. The enotomopathogenic nematodes belongs to the family Heterorhabditidae and Steinernematidae are the efficient biological control agents against insect pests (Gangwar, 2017).
2. **Genetically Modified Organisms (GMOs):** Genetically modified organisms (GMOs) include animals, plants, or microbes that have undergone one or more genetic modifications. In agriculture, transgenic crops are the most prominent example. These crops are engineered primarily to enhance traits such as resistance to pests and diseases,

tolerance to herbicides, and resilience to environmental stresses. Numerous genetically modified insect-resistant crop varieties have been developed, offering an environmentally friendly, user-friendly, and self-sustaining alternative that reduces the reliance on chemical insecticides. Over the years, *Bacillus thuringiensis* (Bt)-based transgenic crops have become a cornerstone in insect pest management, particularly in crops like cotton and maize. (Bigler and Romeis, 2011).

3. **RNA Interference (RNAi):** RNA interference (RNAi) is a natural cellular defense mechanism that involves double-stranded RNA (dsRNA) to suppress gene expression in a sequence-specific manner. Since each species has unique genetic sequences, RNAi can be tailored to target specific species with high precision. While RNAi has shown effectiveness in controlling a wide range of insects across different orders, its application in agriculture faces several challenges. Nonetheless, a significant milestone was achieved with the approval of the first commercial RNAi-based product, SmartStax Pro, developed by Monsanto to target corn pests. This approval by the United States Environmental Protection Agency marks a pivotal moment in the agricultural application of RNAi technology (Christiaens *et. al.*, 2020).
4. **Plant immunization:** Plant immunization is a technique designed to activate the natural defense mechanisms of plants, triggered by either abiotic or biotic factors. This process begins by pre-treating the plant with defense-inducing agents, which stimulate a defensive response and lead to induced systemic resistance against insect pests. Once in this induced state, the plant's resistance is maintained over an extended period, allowing it to respond more rapidly and effectively when faced with actual threats (Kothari and Patel, 2004).
5. **Genome editing with Crispr/cas9:** CRISPR/Cas9 (Clustered Regularly Interspaced Short Palindromic Repeats/CRISPR-associated system) has garnered significant interest for its potential in insect research, particularly in developing insect-resistant plants. This genome editing tool allows precise manipulation of DNA, enabling modifications such as altering target interactions, knocking out susceptible host genes, and disrupting antagonistic defense hormone activities. The CRISPR/Cas9 system works by targeting a specific DNA sequence, making a precise cut at the site, thereby either disabling the gene or replacing it with a new one. The two key components of this system are guide RNA, which directs the Cas9 protein to the exact DNA location, and the Cas protein, which acts as molecular scissors to execute the cut and facilitate the genetic modification (Redman *et. al.*, 2016).

Conclusion

Traditional pest management strategies, predominantly reliant on chemical pesticides, have led to numerous issues such as pesticide resistance, environmental harm, and health risks. An alternative methods include biological control agents, genetically modified organisms, RNA interference, pheromone traps, plant immunization, and CRISPR/Cas9 technology. Each of these approaches offers unique advantages, contributing to more effective and sustainable pest control. The integration of these innovative methods holds great promise for enhancing agricultural productivity while minimizing ecological impacts.

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