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USE OF INTEGRATED MANAGEMENT APPROACHES TO CONTROL *SPODOPTERA EXIGUA* (BEET ARMYWORM): A REVIEW

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Abstract *The destructive impact of Spodoptera exigua Hübner, commonly known as the beet armyworm, plays a pivotal role in substantial economic losses, amounting to as much as 75% (equivalent to an annual value of US$100 billion). This deleterious impact is attributed to the extensive damage inflicted upon cash crops in Pakistan and across the global crop cultivation areas. In addressing the imperative to mitigate the detrimental effects of the beet armyworm, diverse ecologically sustainable management strategies have been identified. Among these, introducing biocontrol agents emerges as a prominent approach, exploiting the pest's natural enemies to regulate its population. Additionally, modern biotechnological techniques, encompassing RNA interference (RNAi), host-plant resistance (HPR), Clustered Regularly Interspaced Short Palindromic Repeats/CRISPR-associated protein 9 (CRISPR/Cas9), and Sterile Insect Technique (SIT), have been actively explored as innovative avenues for pest control. Semiochemical interferences, which involve manipulating insect behavior through chemical signaling and applying insect growth regulators (IGRs), further contribute to the resources with a wide range of applications in management strategies. Moreover, integrating environmentally friendly chemicals, such as biopesticides, is crucial in achieving sustainable and eco-friendly pest control.*

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Introduction

The beet armyworm, *Spodoptera exigua* Hübner (Lepidoptera: Noctuidae), is a serious pest of crops (Ganyard Jr and Brady, 1972) and has a damaging effect on worldwide crop production, especially in America (Burris et al., 1994), Asia, and China. *S. exigua's* destructive feeding behavior on maize and other crops can reduce yields by up to 75% (Compendium). When overwintering occurs, *S. exigua* migrates to other areas to survive and compensate for their population potential (Xia-lin et al., 2011). *S. exigua* was first reported in Northeast Asia in 1876 and rapidly distributed worldwide (Mitchell, 1979). *S. exigua* is known as a cosmopolitan species that attacks and feeds on more than 18 families containing >90 species of plants throughout North America (Pearson, 1983). It was noted on different crops due to their polyphagous behavior. It caused severe damage to plants like cabbage (*Brassica oleracea*), cotton (*Gossypium hirsutum*), bell pepper (*Capsicum annuum*), pea (*Pisum sativum*), okra (*Abelmoschus esculentus* L.), castor (*Ricinus communis L.*) and other cash crops in Pakistan and throughout the growing area (Azidah and Sofian-Azirun, 2006). The presence, devastating effects, and rearing on an artificial diet of *S. exigua* were first reported in 1996 in Tandojam, Pakistan (Anwar et al., 1996) and in 1997 in Andhra Pradesh, India (Khalid Ahmed et al., 1997). Eco-friendly approaches (IPM) were used to control the damaging effects of *S. exigua* populations, including non-chemical controls (biological control, cultural, biotechnological), Insects growth regulators, host plant resistance, and chemical approaches (Hafeez et al., 2021).

Life history and Host plants

S. exigua life cycle is completed in 24-28 days with 6 consecutive larval instars that take 12-18 days and can complete up to 6 generations in the summer (Golikhajeh et al., 2016). The distribution and polyphagous behavior of *S. exigua* on different host plants are shown in Table 1.

Table 1: The distribution of *S. exigua* (Hübner) of different host plants

Plant types	Common name	Scientific name	References
Vegetable plants	Long bean	*Vigna unguiculata sesquipedalis*	(GREENBERG et al., 2005)
	Sugar beet	*Beta vulgaris*	(Bin et al., 2011)
	Castor	*Ricinus communis L.*	(Azidah and Sofian-Azirun, 2006)
	Pea	*Pisum sativum*	
	Cauliflower	*Brassica oleracea var. botrytis*	
	Bell pepper	*Capsicum annuum*	(Greenberg et al., 2001)
Crop plants	Maize	*Zea mays*	(Xia-lin et al., 2011)
	Cotton	*Gossypium hirsutum*	(Azidah and Sofian-Azirun, 2006)
	Safflower	*Carthamus tinctorius*	(Greenberg et al., 2001)
Weeds	Pigweed	*Amaranthus sp*	

Integrated management techniques to control *S. exigua*

Biological control

The use of biocontrol agents like natural enemies, certain entomopathogens (An et al., 2016) (bacteria, fungi, and viruses), and parasitoids were used to control the potential population of agriculture pests and sustain their population below the economic threshold level (ETL) (Reddy, 2011). These approaches sustain the environment and provide an alternative way to control pest populations compared to synthetic chemicals (Cordeiro et al., 2010). The use of predators (natural enemies) like ladybird beetle (*Coccinellidae septempunctata*) gave a way to control and sustain populations below ETL (Symondson et al., 2002) because of their feeding habit on several agricultural pests, including *S. exigua (Evans, 2009)*. Several insects pathogens include baculoviruses (Knox et al., 2015), entomopathogenic fungus (*Beauveria bassiana*) (Shah and Pell, 2003), entomopathogenic nematodes (*Steinernema and Neosteinernema*) (Chitra et al., 2017) and bacteria (*Bacillus thuringiensis*) (Castagnola and Stock, 2014). Certain egg parasitoids (*Trichogramma evanescens*, *Telenomus remus Nixon*) (Mills, 2010) and larval parasitoids (*Hyposoter didymator*, Microplitis spp, and *Meteorus ictericus*) (Sertkaya et al., 2004) were used to control beet armyworm.

Biotechnological control

Biotechnology has considerable participation in controlling the pest population, which is eco-friendly and safe. So far, many methods have been used in biotechnological control to reduce the damage done by serious pest populations. RNA interference (RNAi) (Li et al., 2013), CRISPR/Cas9 (He and Creasey), induction of host plant resistance (HPR) (Zheng et al., 2000), and Sterile insect technique (SIT) (Ware, 2019) employed to control insect pest including *S. exigua*.

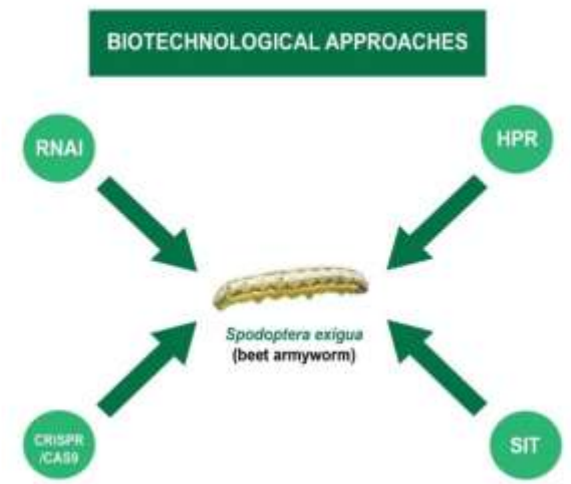

Figure 1: Biotechnological approaches to control *S. exigua*; RNA interference (RNAI); CRISPR/Cas9; Host Plant Resistance (HPR); Sterile insect technique (SIT)

Previous research has shown the mediated emergence of insecticide resistance following prolonged usage, leading to deleterious consequences in response to environmental contamination (Lai and Su, 2011). Modern technology in pest control involves utilizing RNA interference (RNAi) to impede the transcription factor via transcriptional gene silencing (TGS) (Vaucheret, 2006). Recent studies suggest that targeting the trehalose and chitin synthase gene through RNA transfer techniques could effectively control *S. exigua*. These genes are identified as promising candidates for precise and targeted pest control (Chen et al., 2010). Recent advancements in pest control techniques involve the utilization of CRISPR/Cas9 (Bassett et al., 2013), a genome-editing tool that induces mutations in RNA proteins (Li et al., 2018). Studies have demonstrated the efficacy of CRISPR/Cas9 in causing mutations in *S. exigua* (Zuo et al., 2017) through the introduction of the RYRG4946E mutation. This innovative approach holds promise for effective pest management in agriculture. The Sterile Insect Technique (SIT) is an alternative to chemical pest control by inducing sterility in male insects through irradiation or chemical steroids (Kumano et al., 2008). This approach is effective in curtailing pest populations while maintaining safety for non-targeted insects.

Insect Growth Regulators (IGRS)

Insect growth regulators (IGRs) are a class of compounds designed to control insect development by mimicking the functions of key hormones such as chitin synthesis, juvenile hormone, and molting hormone (Naranjo et al., 2004; Tunaz and Uygun, 2004). These regulators manipulate the insects' developmental processes, limiting their growth and leading to mortality.

Table 2: Insect growth regulators and their activity for insect pest control

Chitin Synthesis Inhibitor	Juvenile Hormone Mimic	Juvenile Hormone Analog	Molting Hormone Agonist	Molting Analog	Molting Inhibitor
Buprofezin	Pyriproxyfen	Juvenil hormone III	Halofenozide	Ecdysterone	Diofenolan
Bistfluron	Fenoxycarb	Juvenil hormone III	Chromafenozide	α-ecdysone	
	Epofenonane	Juvenil hormone I			

Semiochemicals

Semiochemicals are chemical substances used in communication between plants, insects, pests, and predators and play a role in controlling pests in IPM (Weatherston and Minks, 1993). It may be inter-species (allelochemicals) or intra-species (Pheromones) (El-Shafie and Faleiro, 2017). The allelochemicals could be allomones (benefits the sender), kairomones (benefits the receiver), synomones (benefit both sender and receiver), and apneumones (signals from abiotic material benefit one entity while posing harm to others) (Kasinger et al., 2008). These are esters, proteins, heterocyclic aromatic compounds, or triglycerides that play a role as semiochemicals (El-Shafie and Faleiro, 2017). Various types of semiochemicals work on a "pull-push" mechanism to target the pest by attracting or repelling it (Reddy and Guerrero, 2004) (Smart et al., 2014). Repellents such as non-host volatiles, sex-pheromones (Landolt and Phillips, 1997), anti-aggregation pheromones, oviposition-deterring pheromones (Wertheim et al., 2005), and alarm pheromones.

Use of eco-friendly chemicals (insecticides)

Insecticides with a low impact on the environment and a high impact on pests are employed to retain pest populations below ETL (Rosell et al., 2008). These insecticides, also known as biopesticides, include natural chemicals (plant extracts) and mixtures of entomopathogens (Schmutterer, 1985). Several eco-friendly insecticides, such as Neem Seed Kernel Extract (NSKE) (Nath et al., 2002) and Abamectin 400FS, are employed against the pest population, especially caterpillars of the genus *Spodoptera* (Tanzubil and McCAFFERY, 1990). These chemicals kill the targeted pest population and conserve non-target organisms and the environment.

Conclusion

The polyphagous nature of the beet armyworm, *Spodoptera exigua* Hübner, has caused significant damage to cash crops, resulting in substantial economic losses and threatening agricultural productivity. Effective control measures are crucial to mitigating its impact, with non-chemical approaches emerging as viable strategies. Natural enemies, like ladybird beetles and parasites, including entomopathogenic bacteria, fungi, viruses, and nematodes, play pivotal roles in biocontrol efforts. Parasitoids, acting on eggs, larvae, or pupae, further aid in suppressing the pest population. Biotechnological approaches, such as RNAi, HPR, SIT, and CRISPR/Cas9 technology, have gained attention for their potential in pest management. These innovative methods offer target-specific interventions, minimizing impacts on non-target organisms. Additionally, insect growth regulators and semiochemicals effectively control the beet armyworm, ensuring precision and harmlessness to beneficial organisms. Adopting these multifaceted and targeted control techniques is essential for sustainable pest management, safeguarding agricultural yields, and mitigating economic losses associated with the destructive behavior of the beet armyworm.

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Declarations

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All data generated or analyzed during the study are included in the manuscript.

Ethics approval and consent to participate

Not applicable

Consent for publication

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Conflict of Interest

Regarding conflicts of interest, the authors state that their research was carried out independently without any affiliations or financial ties that could raise concerns about biases.