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Review Article

Greasy cutworm (*Agrotis ipsilon*) and its biorational management strategies: A review

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ABSTRACT: *Agrotis ipsilon* (Lepidoptera:Noctuidae) known as greasy cutworm is an important destructive polyphagous pest of many crops distributed throughout the world. Larvae are polyphagous with a wide and diverse host range, as a result of which they cause extensive damage to a wide range of agricultural and horticultural crops, mainly at the seedling stage. Insecticide resistance has grown as a result of the widespread and arbitrary use of pesticides, and pesticide residues have accumulated in food. There is a growing need for new pest management strategies to limit the threat to humans, the environment, and non-target organisms as a result of these pests. This review encompasses the use of biorational compounds for the management of this pest. It could offer a broad perspective to direct the search for novel pesticidal tactics against *A. ipsilon* that are focused on environmental sustainability.

KEYWORDS: Biorational compounds, cutworm, management, pest, polyphagous

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INTRODUCTION

Agrotis is a widely distributed genus of cutworms with around 300 species identified (Medeiros *et al.*, 2019). Cutworms are found in various places throughout the countries of the continents of Africa, Asia, Europe, North America, Oceania, and South America (Rodingpuia and Lalthanzara, 2021). In India, 26 species are known to occur with *Agrotis ipsilon, Agrotis segetum,* and *Agrotis flammatra* being the most common (Chandel *et al.*, 2021). Cutworms such as *Agrotis*sp., *Peridomasaucia, Spodoptera frugiperda, S. exigua*, and *S. littoralis* cause significant damage to most economic plants. The majority of agriculturally important cutworms belong to the genus *Agrotis*, and the most harmful species of this genus include: *A. ipsilon, A. flammatra, A. plecta, A. longidentifera*, and *A. segetum* have been found in India (Chandel *et al.* 2013). The extent of the damage caused by this pest to vegetable crops, including capsicum (65.73%), bitter gourd (58.65%), french bean (40.64%), brinjal (35.41%), cucumber (32.65%), pea (31.05%), tomato (30.71%), cabbage (29.41%), and cauliflower (21.95%), has been noted in endemic areas of the North-Western Himalaya (Kumar *et al.,* 2007).

More than one hundred different crops worldwide can be destroyed by *Agrotis ipsilon* (Lepidoptera: Noctuidae), commonly known as the black cutworm. Cutworm is a nocturnal pest, the larva damages seedlings at night. They damage the plants by cutting the stems just above the ground level. During the day, cutworm larvae hide and reside inside cracks and crevices in the earth (Shakur *et al.*, 2007). The larvae can cause significant damage to plants when they are in their fourth to sixth instars. Cutworms coil up tightly into a 'C' shape when disturbed. It has a habit of chewing through the stem of seeding at ground level. Cutworms hide during the day and feed at night. They may move the cut plants beneath the soil and feed on them in day time (Joshi *et al.*, 2020). One larva can consume several plants in a single night (Showers,1997). Black cutworms are a polyphagous species that damage a variety of vegetables, grains, cotton, and corn. This species has a distinct way of life and behaviour. The dietary ecology and behavioural traits of larvae and adults differ greatly. The larvae of the black cutworm consume practically all types of vegetables as well as many commercially important crops by cutting the seedlings, whereas the adults predominantly consume plant-produced food supplements like nectar and pollen. The broad range of host plants and the fast-evolving pesticide resistance are the only factors where *A. ipsilon* has a substantial adaption (Showers, 1997; Binning *et al.*, 2015).

In this work, we reviewed the use of biorational chemicals, plant extracts, biocontrol agents, insect growth regulators, and nanoparticles implemented or proposed as new strategies for controlling *A. ipsilon*.

Life history of *Agrotis ipsilon*

The lifecycle of *A. ipsilon* consists of four stages: the egg, the larva, the pupa, and the adult. Figure 1. The egg is white at first, but as it ages, it turns brown. Approximately spherical in shape, they have a slightly flattened base that measures 0.43 to 0.50 mm in diameter and 0.51 to 0.58 mm in height. The egg has 35 to 40 ribs radiating from the tip, which alternately lengthens and shortens. The eggs are usually laid in bunches on the leaves. Females can lay between 1200 and 1900 eggs. The incubation period of eggs ranges between 3-6 days (Joshi and Solanki, 2020). There were seven larval instars. Head capsule widths are about 0.30-0.34, 0.45-0.52, 0.80-0.85, 1.30-1.40, 2.20-2.50, and 3.00-3.40 mm for instars one through six respectively. Larval body length is reported to be 1.8-2.3, 3.1-4.6, 5.5-7.2, 7.9-8.7, 14.0-20.0, 30.00-36.66 mm, and body width is 0.35-0.52, 0.60-0.83, 0.91-1.3, 1.5-2.2, 2.3-3.5, 3.5-4.8 through one to six instar respectively (Pathania, 2010). Larvae appeared grey to nearly black in colour. The larval stage lasted for 29-44 days. In most cases, larvae remain on the plant until they reach the fourth instar of their development when they become photo-negative and they rest in the soil during the day. Additionally, they tend to serve plants at the soil surface during these later instars, which results in the plant tissue being dragged below ground. Insect larvae frequently exhibit a high degree of cannibalistic behaviour (Capinera, 2007). It is estimated that pupation takes place at a depth of 3-12 cm below the surface of the ground. The dark brown pupa is 17 to 22 mm long and 5 to 6 mm broad. The pupal stage usually lasts 12 to 20 days (Capinera, 2007). An adult's wingspan ranges in size from 36 to 55 mm. The outer one-third (the distal half) of the forewings is significantly lighter than the inner two-thirds, which are typically mahogany brown to dark brown in colour. In contrast to a male's uniformly bipectinate antennae and sparsely spined top portion of the anterior tibia, a female has filiform antennae (Edde, 2022). Adults feed on nectar from flowers.

Management strategies

A. ipsilon is one of the most challenging agricultural pests when it comes to control and management. Larvae remain buried in the ground throughout the day, posing difficulty in their control. To effectively manage cutworms, different management techniques are being used Figure 2.

Biopesticides

Biopesticides are derived from living things that are found in nature, including animals, plants, and microorganisms (such as bacteria, fungi, and viruses). They are becoming more important around the world as they can effectively control serious plant-damaging insect pests. In order to control pests, biopesticides, and their by-products are mostly used (Mazid *et al.,* 2011).

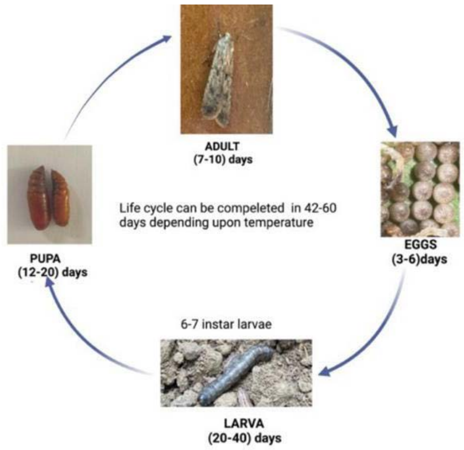

Figure 1. The life cycle of *Agrotis ipsilon* consists of egg, larvae, pupa, and adult.

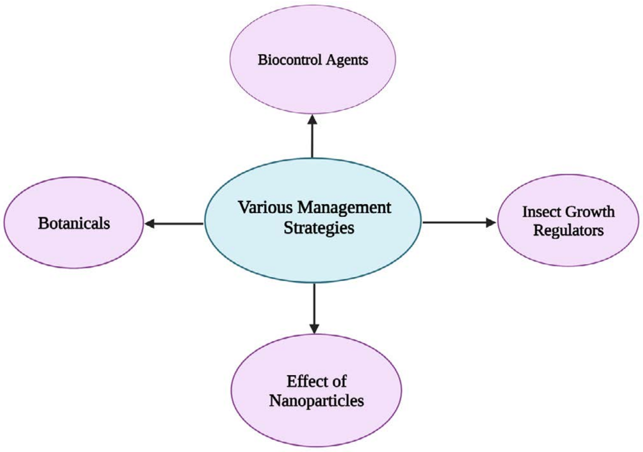

Figure 2. Various control methods against black cutworm, *Agrotis ipsilon.*

Entomopathogenic nematodes

Nematodes that are pathogenic to insects are termed Entomopathogenic Nematodes (EPNs) that are related to the Heterorhabditidae and *Steinernematidae* families, respectively. EPNs survive in mutualistic relationships with entomopathogenic bacteria *Xenorhabdus* and *Photorhabdus*. During their life cycle, infectious EPN juveniles carry an intestinal symbiont into their insect hosts through the natural opening of the hemocoel, where the bacterial population multiplies in a logarithmic way. By introducing toxins, metabolites, and antibiotics to the cadaver, the bacteria produce toxins, metabolites, and antibiotics that will kill the insects within 24 to 48 hours, thereby creating a safe environment for the survival of nematodes (Singh *et al.*, 2022). The efficacy of EPNs against *Agrotis ipsilon* was assessed by Fetoh *et al,* (2009) in laboratory and field conditions. The larvae and pupae treated with *Steinernema carpocapsae* caused mortality ranged from (70-100 %) and (50-100 %), respectively, while larvae and pupae treated with *Heterorahabditis bacteriophora* nematode caused mortality ranged from (80-100 %) and (70-100 %), respectively. The percentage mortality with *Steinernema carpocapsae* was 70% in field conditions (Fetoh *et al.*, 2009). Under mild summer temperatures, *S. carpocapsae* and *S. feltiae* were able to effectively manage black cutworms inonolf course turf (Ebssa and Koppenhöfer, 2011). There is also a report that *Steinernema carpocapsae* is the most virulent species of the genus *Steinernema* in pots containing grass followed by *H. megidis, H. bacteriophora*, and *S. riobrave* (Ebssa and Koppenhöfer, 2012). In another study, the effect of three strains of Steinernematid and two strains of Heterorhabditid nematodes was evaluated, *S. riobravis* had the greatest potential to cause 50% mortality (LD50) with 116 infective juveniles. *Steinernema* sp. Mexican strain and *Steinernema riobravis* were more effective with LD90 values of 620 and 634 infective nematodes juveniles, respectively. Whereas, *S. carpocapsae* Mex and *H. indica* LN2 were virulent, causing 80.0 and 83.3% mortality, respectively, to the third instar larvae after 72 h infection at 25°C in *in-vitro* condition. Both EPNs are capable of reducing the damage caused by *A. ipsilon* in the field at the application of 2×10^9 IJ ha^{-1} (Yan *et al.*, 2014).

Similarly, the efficacy of EPNs was investigated under laboratory and greenhouse conditions. With increasing infective juvenile concentration and exposure time, mortality percentage increased noticeably, reaching up to 100% and 90% at 160 (IJs), after 72 hours of exposure in *S. carpocapsae* and *H. bacteriophora*, respectively. *S. carpocapsae* had a greater virulence against the last instar larvae of *A. ipsilon* (Mahmoud and Mahfouz, 2016). The control of cutworms under laboratory and glasshouse conditions was observed to be effective, *H. india* registered the highest LC50 of 16.39 IJs/larva and LT50 of 28.69 h/larva, while *S. glaser* registered the lowest LC50 of 18.03 IJs/larva and LT50 of 23.98 h/larva against *A. ipsilon* (Radhakrishnan *et al*., 2017). EPNs are a biological control agent that is highly effective against insects found in soil, such as *A. ipsilon.* In a laboratory experiment, the highest mortality rate (100%) was reached within 2 days after treatment by *H. bacteriophora* (FLH-4-H) and *H. indica* (216-H) isolates at concentrations of 50 and 100 IJs/cm^2. The lethal concentration values (LC50 and LC90) of the *A. ipsilon* larval population were 52 IJs and 129 IJs. It has been shown that all native EPN isolates can be used to control *A. ipsilon* via biological control, as evidenced by the results of this study (Yuksel and Canhilal, 2018). In a field experiment application of *H. bacteriophora* at 5.0 x 109 IJs/ha leads to the lowest tuber damage and the highest yield was observed as compared to the untreated control (Devi *et al.*, 2021). Bhairavi *et al.* (2021) reported that after 144 hours, *H. bacteriophora* recorded maximum mortality with the application of 300 IJs/larvae. Whereas *S. aciari* demonstrated a 100% mortality rate at 300 IJs/larva after 168 hours. For *H. bacteriophora*, the LD50 and LT50 values were 35.711 IJs/larva and 83.050 h. For *S. aciari*, the lowest LD50 and LT50 values were 71.192 IJs/larvae and 97.921 h, respectively. Similarly, *Heterorhabditis* spp. isolated from Egyptian clover (*Trifolium alexandrinum*) TAN5 was able to cause percentage mortality ranging from 24 to 100% in 3rd instar larvae and 16-80% in pupae of *A. ipsilon* at different concentrations after 5 days of treatment, while nematode isolated from guava trees (*Psidium guajava*) PGN6 was able to cause mortality ranging from 18 to 96% in larvae and 14 to 72% in pupae. TAN5 and PGN6 recorded LC50 values of 1285.527 and 1560.747 IJs/cup, respectively (Nouh, 2021).

Entomopathogenic fungi

Entomopathogenic fungi are fungi that cause disease in insects. Three entomopathogenic fungi *Beauveria bassiana, Metarhizium anisopliae,* and *Verticilliun lecanii* were evaluated against *A. ipsilon, Beauveria bassiana* at 2 x 10^3 spore/ml was more effective (Abdel-Raheem *et al*., 2016). El-Hawary (2009) observed that the larvae of *A. ipsilon* treated with Priority (*Paecilomyces fumosoroseus*) at 1x10^9 spores concentration resulted in 100% mortality in 5.3 days. The pathogenicity of two entomopathogenic fungi was observed on larvae of *A. ipsilon*, the formation of white spores indicated the growth of *B. bassiana* at LC50 (2 10^8 spore/ml) after 7 days, the formation of green spore after 15 days at LC50 (1.9 10^8 spore/ml) on the cadaver of larval pupal intermediate indicated the growth of *M. anisopliae* (Gabarty *et al*., 2014). Similarly, the Entomopathogenic Fungi (EPFs), *Beauveria bassiana* isolates were evaluated against the last instar larvae of *A. ipsilon*, and after 14 days (48 and 100%) mortality was observed at concentrations of 9.2×10^4 and 2.9×10^6 spores/ml, respectively (Ahmed *et al*., 2022).

Botanicals

Botanical pesticides are plant-derived chemicals that repel, hinder, or kill pests. The secondary metabolites found in botanical pesticides are well known for their antifungal, antibacterial, antioxidant, and insecticidal properties. Secondary metabolites found in these pesticides include steroids, alkaloids, tannins, terpenes, phenols, flavonoids, and resins (Ahmad, Singh and Kumar, 2017). Plant products are known to have deleterious effects on insects in several ways, such as growth inhibition, disturbance of reproductive behaviour, and suppression of reproduction behaviour (decrease of fecundity and fertility), as well as toxicity, mortality, antifeedant growth inhibitors, and suppression of reproductive behaviour (Hernández-Lambraño, Caballero-Gallardo and Olivero-Verbel, 2014). The antifeeding and insecticidal activity of two essential oil was observed, the antifeeding activity of eucalyptus oil was found to be 96.24% at 2% and the insecticidal activity was 60.24%. Whereas the antifeedant activity of gaultheria oil at 2% was 87.21% higher insecticidal activity was found in gaultheria oil at 86.92% Adult emergence deteriorated and deformities were also observed (Jeyasankar, 2012). Similarly, the larvicidal activity of basil essential oil against *A. ipsilon* was evaluated. The larvicidal effect was stronger at 3%, only 35% of the larvae reached the pupal stage with a 67.16% reduction as compared to the control and 13% of the pupae were malformed. Eugenol killed 40% of the treated larvae. At 3% and 2% basil, the percentage of adult emergence was reduced by 76.84 and 54.74%, respectively. Adult abnormalities reached 11% and 7%, respectively, at 3% and 2% basil (Shadia *et al.*, 2007). The effect of five essential oils (Garlic, Mint, Cumin, Caraway, and Parsley) of different concentrations was evaluated on third-instar larvae of *Agrotis ipsilon*. A number of the tested oils exhibited antifeedant and starvation properties. A combination of garlic oil, mint oil, cucumber, caraway, and parsley oil possesses toxic properties (Sharaby and El-nojiban, 2015). In another study, the toxic effect of some plant extracts (*Conyza aegyptiaca*, *Melia azedarach*, and *Vinca rosa*) at 5% concentration resulted in a considerable reduction in the total protein, lipids, and carbohydrates, in larval hemolymph. Despite the low concentration of compounds present, these compounds can be hazardous to larvae in terms of survival, food consumption, and enzyme activities (Ramadan, 2020). Similarly, the toxicity of lemon grass essential oil revealed that detoxification enzyme activity resulted in the inhibition of CarE and GST enzyme and oxidative stress indicates a significant increase in CAT and lipid peroxidase enzyme activity after 96 h post-treatment at the LC15 427.67 and LC50 2623.06 mg/L (Moustafa *et al.*, 2021). The anti-nutritional effect of five wild botanicals was assessed among which *A. judaica, M. longifolia, and O. syriacum*, were more effective. As a result of the toxic oil, the consumption of food decreased, thereby causing a significant decrease in the Relative Consumption Rate (RCR), Growth Rate (RGR), and the Efficiency of Food Conversion (ECI)/Digested (ECD), as well as an increase in Metabolic Cost (MC), and antifeeding activities (Nasr, Teleb and Abou-Saty, 2021). The acetone extract of *Melia azedarach* at LC50 (46.80×10^3 ppm) inhibits *A. ipsilon* larval development by lowering total lipid, protein, carbohydrate trehalase, invertase, and transaminase activity (Shaurub, El-Sheikh and Shukshuk, 2022).

Insect growth regulators

Among the main classes of Insect Growth Regulators (IGRs) that are used as biorational agents, Chitin Synthesis Inhibitors (CSIs), ecdysone agonists (20Es), and Juvenile Hormone Analogs (JHAs) were reported to be the most effective compounds against *A. ipsilon* (Gilbert, and Gill, 2005) The effect of Triflumuron (Alsystin) was examined against *A. ipsilon* which drastically depressed the developmental rate. Larval-pupal intermediates were formed at the lowest concentration, lipid content was decreased at all the tested levels of concentrations. The gut epithelium was destroyed histopathologically and the basement was separated to varying degrees depending on the concentration level (Abdel-Hakim *et al.*, 2016). In another study, the juvenile hormone analog (Methoprene) effect was studied against *Agrotis ipsilon* in which developmental duration had been slightly extended and some pupal-adult intermediates had been produced. As a result of the destruction of intestinal epithelium as well as the separation of the basement membrane from the epithelium, the content of total proteins and total lipids slightly increased (Abdou and Abdel-hakim, 2017). Acute toxicity of Pyriproxyfen against larvae was found to be present, as well as chronic toxicity against pupae and adults. At an LC50 value of 65.9 against 4th instar larvae, larval and pupal durations were considerably extended. Failure of ecdysis disturbed development and suppressed the pupation (Bakr *et al.*, 2021). Similarly, Flufenoxuron and pyriproxyfen's effects on survival, intermediary metabolism parameters, and hemocyte profile were evaluated. Flufenoxuron at LC50 (3.04 ppm) lowered the hemolymph total protein content whereas pyriproxyfen at LC50 (168.70 ppm) lowered the total protein, lipid, and carbohydrate, and a decrease in total hemocyte count was recorded. Transaminase activity and phagocytic plasmatocyte numbers were reduced in both the tested compounds (Shaurub, El-Sheikh and Shukshuk, 2022).

Effect of nanoparticles

Nanotechnology is one of the most innovative and promising new strategies for pest management that is available today. Nano-based innovative pesticide formulations over the past ten years, including nanoemulsion, nanosuspension, nanocapsules, and metallic oxide NPs. These materials were more effective at controlling pests than conventional ones and with less adverse environmental effects (Buffle, 2006; Owolade and Ogunleti, 2008). Silica nanoparticle bait containing various doses resulted in the highest percentage of larvae mortality (100%) after 15 days of application (Mesbah *et al.*, 2020). Different nano-formulation of the two botanicals neem and peppermint had a strong larvicidal impact on the 2nd and 4th larval instars of *A. ipsilon* (Dimetry *et al.*, 2019). Geranium oil loaded-solid lipid nanoparticles provided a significant percentage of mortality at (5.0 and 2.5%) concentrations (Adel *et al.*, 2019).

CONCLUSION

Cutworms are polyphagous, attacking a wide range of crops all across the world, including India. Many researchers have conducted laboratory and field investigations to evaluate various pesticidal groups against *A. ipsilon,* concluding that some pesticides have a high capacity to control this pest. Various management strategies are used to control cutworm infestations in places where they are prevalent. Due to the cutworm larvae's tendency to hide during the day and resilience to the majority of pesticides, chemical treatment against these pests is frequently ineffective and remains insufficient. Additionally, the harmful effects of the substances have prompted researchers to look for other alternative management strategies for environmental friendly management of insect pests, biorational techniques involving botanical preparations, natural products, insect growth regulators, and entomopathogenic nematodes are gaining more importance in the recent days. Therefore, biorational compounds present a safe and IPM-compatible alternative to chemical pesticides for the management of cutworms.

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AUTHOR CONTRIBUTIONS

SK: conceptualization; JY: data analysis, curation, and validation; KC, KR, PK: data interpretation and literature review; JY: original draft preparation; SK: editing, final draft preparation, and critical revision.

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