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The potency of chemical insecticides in management of cutworm, *Agrotis ipsilon* Hufnagel (Noctuidae: Lepidoptera): A review

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Abstract
The black cutworm, *Agrotis ipsilon* (Lepidoptera: Noctuidae), is ubiquitous in many countries around the globe. It is one of the most aggressive underground insect species which feeds on more than 100 host crops. The traditional control methods for this species were not considered promising. Therefore we can develop a good management framework by incorporation of chemical control for the reduction of this pest. Some pesticidal groups *viz*., synthetic pyrethroids, carbamates, organophosphates and neonicotinoids etc., were used primarily to protect crops from cutworms. However, in case of injudicious use, these chemicals may have a detrimental impact on human health and natural environment. In addition to this, frequent use of the same chemicals may cause insect resistance to particular insecticides. The effects of such compounds should be monitored to avoid the occurrence of harmful impacts of insecticides on the surroundings. Thus, this review discusses the efficacy, sub-lethal impact and corrects methods of applying different chemicals as an essential part of integrated management (IPM) of cutworm.

Keywords: *Agrotis ipsilon*, chemical insecticides, cutworm, management, IPM

Introduction

The black cutworm, *Agrotis ipsilon* (Hufnagel) (Lepidoptera: Noctuidae), is highly polyphagous and attacks a large number of crops worldwide including India (Ram *et al*., 2001; Binning *et al*., 2015) [25, 6]. It constitutes a major group of insect pests because of the damage they inflicts to a large number of agricultural crops and their wide distribution (Vendramim *et al*., 1982) [40]. It is one of the most dangerous species of underground pests and can feed on more than 100 host plants *viz*., corn, wheat, cotton, soybean, vegetables and a variety of weeds (Liu *et al*., 2015) [21]. It has habit of cutting off a seedling at ground level by chewing through the stem and got their name from this habit. One larva can have the ability of cutting off several plant seedlings in a night. Sometimes they drag the cut plant parts beneath the soil and feed upon them during day time. When disturbed, the cutworms typically coil up tightly into 'C' shape. The cutworms usually remain hidden during the day and feed mostly at night. In particular, *A. ipsilon* larvae can cause serious damage at the fourth-sixth and/or higher instar stages (Showers, 1997) [34]. *A. ipsilon* and *A. segetum* (Denis & Schiffermuller) were found to be feeding on various crops (3–18% infestation) in Himachal Pradesh, India (Verma and Verma, 2002) [41]. The economically important cutworms are belonging to genus *Agrotis*, *Euxoa*, *Discestra* and *Peridroma* of family Noctuidae and order Lepidoptera. The genus *Agrotis* includes number of species of cutworms which cause extensive damage to vegetable and cereal crops in India (Ram *et al*., 2001) [25].

Various methods such as deep ploughing, flooding and manual collection of larvae were adopted for the control of cutworms. The microbial insecticides have also been tried under field conditions in Himachal Pradesh, India for the control of *A. ipsilon* and *A. segetum* in cabbage, but were not found promising for the management of this pest (Anonymous, 2004) [1]. These management practices are very important but cannot produce better results alone against this pest. Therefore we can develop a good management framework by incorporation of chemical control for the reduction of this pest. The pest can result in concealed damage on fields, and insecticides difficult to fully expose the pests by spraying, leading to reduced control strategies performance.

The selection of highly efficient insecticides and suitable methods of application is currently a major problem in the development of integrated pest management (IPM) strategies to control the black cutworm (Falin *et al*., 2019) [12]. For more than 50 years now, pest control treatment has been the dominant method of killing insect organizations with toxic chemicals. There continue to be safety issues and environmental degradation and renewed demands for secure, cleaner and cost-effective alternatives. The toxicity and future efficacy of insecticides in the management of insect pests can be measured and projected using bioactivity changes (Silva *et al*., 2016) [36]. Thus, this review discusses the efficacy, sub-lethal impact and corrects method of applying different chemicals as an essential part of cutworm IPM.

Chemical Pesticides/ Insecticides

Chemical compounds and synthetically and naturally occurring mixed compounds are generally called pesticides or insecticides. When selecting and formulating the pesticide, it is important to consider its biological effectiveness in the battle against a pest, the vulnerability of the target organism, application methods, protection for human beings and its toxicity to non-target organisms (including residual activities, where appropriate). Our goal is to reduce or completely eradicate pests, diseases and weeds by using chemical pesticides. The control of plant growth can also be influenced by pesticides. The number of pesticides used worldwide is immense. There are over 1000 different types of pesticides containing biologically active substances. Pesticides play an important role in agricultural production quality and productivity; they often affect the environment in a positive way, and sadly not always.

Potency of Chemical Insecticides

Laboratory studies on different chemicals against *A. ipsilon*

Bioassay studies of insecticides against cutworm

Laboratory bioassays are generally conducted to assess the toxicity of any insecticide against any specific pest. These bioassays play an important role as they are less time consuming and in very short period of time one can obtain comparative toxicity data of various insecticides (Paramasivam and Selvi, 2017) [24]. In China, the toxicity of 18 insecticides to *A. ipsilon* was investigated in the laboratory by topical application to 5th instar larvae. The cutworm was found to be very sensitive to pyrethroids (LD_{50}: 0.03-0.27 µg/ g), less sensitive to organophosphate compounds (LD_{50}: 3.21-250.20 µg/ g) and extremely tolerant to carbamates (LD_{50}: 86.50-638.50 µg / g) (Han, 1986) [15]. In another study, carbamates were found less effective than organophosphates when applied either as treated leaves or poison baits on the 5th instar larvae of *A. ipsilon* (Elham and El-Sayed, 1991) [10]. In another study, Baxendale *et al.* (2001) [4] reported that 100 per cent mortality was obtained with all the insecticides *viz*., pyrethroids like deltamethrin, lambda-cyhalothrin and bifenthrin as well as chlorpyriphos when the cutworms were introduced into the polyvinyl chloride (PVC) cylinders on the day of treatment. Salama and Moawed (1988) [29] found that the deltamethrin was found to be most toxic compound against 2nd-instar larvae with an LC_{50} of 0.25ppm, followed by cypermethrin and fenvalerate (LC_{50} 0.77 and 14, respectively). Ricci *et al.* (2002) [27] carried out laboratory bioassay and found that the deltamethrin showed 11 fold superior activities on *A. ipsilon*. Toxicity of four synthetic pyrethroids and chlorpyriphos was evaluated against 1-2 days and 8-9 days old larvae of *A. ipsilon* using dry film technique. The order of toxicity on the basis of LC_{50} values (ppm) to 1-2 days old larvae was cypermethrin (0.0212) > deltamethrin (0.0296) > alphamethrin (0.2031) > fenvalerate (0.2295) > chlorpyrifos (0.6851). The LC_{50} values of cypermethrin, deltamethrin, alphamethrin, fenvalerate and chlorpyrifos against 8-9 days old larvae were 0.1210, 0.1346, 0.8241, 0.9321 and 2.4561ppm, respectively (Kumar and Kumar, 2012) [20]. In laboratory trials, Hussein *et al*. (2005) [17] studied the effect of bio-insecticide, spinosad on the cutworm, *A. ipsilon*. As a result spinosad was considered a better option against *A. ipsilon*. Temple *et al*. (2009) [38] found that lepidopteran larvae of all the species demonstrated similar susceptibility to rynaxypyr in insecticide treated diet bioassay with LC_{50} values ranging from 0.02-0.09 ppm and in topical method of bioassay with LD_{50} values ranging from 0.52-1.52 µg/ g larval weight. Gosselin *et al*. (2009) [13] found that the third instar larvae of *A. ipsilon* were highly susceptible to spinosad, with an estimated LC_{50} of 50ppm. Topical applications of 5, 7.5 and 10 ppm of spinosad on third instar larvae reduced larval size and increased time to pupation and adult emergence. The result indicated that spinosad is a promising tool for controlling black cutworm larvae alone or in combination with other products. Toxicity of six insecticides was evaluated against black cutworm, *Agrotis ipsilon* using leaf-dip method and results showed that the toxicity of chlorfenapyr, indoxacarb and emamectin benzoate were significantly higher than that of chlorpyrifos, phoxim and lambda cyhalothrin (Yu *et al*. (2012) [45]. Sharma and Verma (2013) [33] evaluated six insecticides (bifenthrin, clothianidin, flubendamide, indoxacarb, thiamethoxam and thiodocarb) against the cutworm. Amongst these, bifenthrin was found most effective with LC_{50} values of 0.009 and 0.089 ppm for third and sixth instar larvae, respectively. Du *et al*. (2013) [9] revealed that the toxicity of chlorantraniliprole and flubendiamide were significantly higher than that of other insecticides. In another study, Wang *et al*. (2014) [43] found that the cyantraniliprole and chlorantraniliprole had no bioactivity to eggs, but could reduce the survival rate of larvae. The LC_{50} values of chlorantraniliprole to 3rd instar larvae of *A.ipsilon* were 0.663ppm. Rimpy and Verma (2018) [28] revealed that all the seven tested insecticides caused mortality of third instar larvae of both the species upto 15th day of spray except emamectin benzoate and cypermethrin, where the mortality was recorded upto 10th and 7th day of spray, respectively. Flubendiamide 0.004% showed highest PT value of 1099.98 and 1125 against the third instar larvae of *A. ipsilon* and *A. segetum*, respectively. The relative toxicity serves as a ready reckoner for the selection of suitable insecticides for effective pest management under field conditions. Also, such baseline data provides a record for detecting resistance levels of insects if any, to various insecticides at different periods.

Sub-lethal insecticidal effect of chemicals against cutworms

When target pests are not killed immediately after the application of insecticides in the field; sub-lethal effects, such as physiological and behavioral changes, could appear as the dose of insecticide is reduced over time (Rehan and Freed, 2015) [26]. Therefore, sub-lethal doses of insecticides could have a large influence on insect emergence rate, sex ratio, pupal weight, adult reproduction and the duration of larvae and pupae (Han *et al*., 2012) [14]. This strategy could reduce both the application frequency and total amount of pesticides used, which would aid in reducing both cost of control and environmental pollution. In the lab study, Salama and Moawed (1988) [29] found that the virus synergistically affected the insecticides such as cypermethrin, deltamedhrin and fenvalarate at sublethal concentrations ($\leq LC_{25}$). Compared to controls, LC_5, LC_{20} and LC_{40}; sublethal doses of cyantraniprole have extended larval and pupal length, and extended average and preovipositional overall production. Moreover, longevity, reproductive benefit, intrinsic and limited increases and net reproductive rate decreased significantly (Xu *et al*., 2016) [44]. Hanan *et al*., (2017) [16] found the induce of morphological abnormalities of chlorfluazuron and diflubenzuron compounds in all stages, increasing larval and pupa length, and reducing longevity and fertility. Falin *et al*., (2019) [12] has tested its sublethal effect on nutritional physiology, enzyme properties and population parameters of novel anthranilic diamide, chlorantraniliprole. Suggesting that low concentrations of chlorantraniliprole can decrease developmental length, normal eating and digestion, fertility as well as populations of *A. ipsilon*. The ability to be used as a control mechanism for this cutworm is demonstrated by chlorantraniliprole. Sigrun *et al*., (2011) [35] studied the efficacy of clothianidin as a seed treatment at two commercially available levels and their interaction with a transgenic corn hybrid (Bt maize), finding that clothianidin increased larval mortality at a rate of 25 mg kernel^{-1} on Bt maize and decreased larval weight gains additively. By comparison, larvae weights fed on non-Bt maize seedlings treated with clothianidin at a rate of 25 mg kernel^{-1} significantly increased, indicating either compensatory over consumption, hormesis or hormoligosis. Both Bt maize alone and clothianidin added to non-Bt maize seedlings at a rate of 125 mg kernel^{-1} caused increased mortality and decreased weight gains for the larval. El-Sayed *et al*., (2018) [11] investigated the effect on certain developmental and reproductive parameters of *A. ipsilon* of two benzoyl-ureas (chitin synthesis inhibitors), namely chlorfluazuron and flufenoxuron, and found that chlorfluazuron and flufenoxuron significantly decreased the mean total protein, carbohydrate and lipid content in the ovaries compared to untreated insects, with the exception of insignificant decrease in ovaries. Additionally, it substantially atrophied the total ovariolar duration. Additionally, by affecting its development and reproductive capacity, they may reduce the population size of this insect species.

Field evaluation of different insecticides against *A. ipsilon*

Potential of insecticides to control cutworm in agriculturally important crops

Potato

Nagia and Verma (1985) [23] evaluated 11 insecticides against *A. ipsilon* in potato and found that the foliar application of chlorpyrifos, carbaryl, endosulfan and quinalphos gave good protection of potato tubers. Mohan *et al.* (1989) [22] conducted field experiments to evaluate the relative efficacy of aldrin, chlorpyrifos, carbaryl and endosulfan for the control of *A. ipsilon* on potato and found that spraying of carbaryl at 2 kg/ ha was most effective in controlling the cutworm. Zaki *et al*. (2007) [46] found that among treated insecticides, imidacloprid recorded the least damage (2.75%) in potato due to cutworms. Badiyala and Sharma (2007) [2] observed that the basal application gave significantly less incidence of *A. ipsilon* compared to foliar treatments. Among basal application, chlorpyrifos (400g a.i./ha) proved highly effective in reducing tuber damage. Kumar *et al*. (2009) [2] found Lambda-cyhalothrin most effective when applied either as spray or drench. Sharma (2014) [31] evaluated six insecticides, *viz*; chlorpyrifos (0.05%), imidacloprid (0.0178%), lambda cyhalothrin (0.004%), profenofos (0.05%), quinalphos (0.05%) and triazophos (0.04%) in field conditions against cutworm on potato and results indicated that all the evaluated insecticides were effective and highest increase in tuber yield was recorded in case of profenofos (0.05%).

Maize

A field trial was conducted to test the efficacy of certain insecticides in *A. ipsilon* management on Pioneer Maize (K-85) and found that seed treatment with chlorpyriphos, imidacloprid and chlorpyriphos application of insecticidal dust was due to higher yields and lower plant mortality compared with other treatments (Bhagat *et al*. 2008) [5]. Seed treatment with chlorpyrifos 20 EC @ 5 g a.i./kg seed, imidacloprid 70 WP @ 3.5 g a.i./kg seed and chlorpyrifos insecticide application 1.5 per cent D @ 25 kg / ha resulted in higher yield and lower plant mortality compared to other treatments and control (Viji and Bhagat, 2001) [42].

Tobacco

The pyrethroids, cypermethrin, fenvalerate and permethrin were more effective and lasting than organophosphorus insecticides viz., sulfopros, chlorpyrifos, and trichlorfon. The higher dose of cypermethrin and fenvalerate produced a longer protective time than the lower rate of the same materials and both materials lasted longer than permethrin against cutworm larvae (Cheng, 1980) [7]. Cheng and Hanlon (1990) [8] evaluated the efficacy of five insecticides *viz*., alphamethrin 100 EC, cyfluthrin 240 EC, lambda-cyhalothrin 50 EC, fluvalinate 240 EC and cypermethrin 400 EC against cutworm. All the insecticides tested were equally effective, except for fluvalinate applied to the soil surface at 112 g a.i./ha, which was less effective. In a field experiment, six insecticides were evaluated for the control of *A. ipsilon*. All of them produced similar levels of control. These were edron and thioluxon, deltamethrin (Decis), cypermethrin (Ripcord), cyfluthrin (Baythroid), methyl parathion (Metacide) (Khan *et al*., 1997) [18].

Sunflower

A field trial was conducted to evaluate pre-sowing application of six soil insecticides against Agrotis ipsilon in sunflowers. Application of lindane granules and lindane dust resulted in the lowest population (0.0 and 0.33 larva, respectively) and proved significantly more effective than the control and the other treatments. The next best treatments were phorate and diazinon (Thakur *et al*., 1997) [39]. Bakhetia and Arora (1995) [3] studied the use of different insecticides (chlorpyrifos, imidacloprid, quinalphos and cypermethrin) for the control of *A. ipsilon* on sunflower under field conditions and found that all the treatments provided cent per cent reduction of cutworms.

Cruciferous Vegetables

Talpur *et al*. (2002) [37] found that the cypermethrin was most effective against greasy cutworm on cauliflower. The specific insecticide, methyl parathion was also equally effective in controlling this insect pest. All the insecticides lost their effectiveness after 24 hours of spraying, however, methyl parathion was persistent up to two weeks of application. Sharma (2014)a [32] evaluated five insecticides as foliar sprays for managing cutworms in transplanted cauliflower revealed that deltamethrin 1% + triazophos 35 EC (1.0 mL L^{-1}), chlorpyriphos 20 EC (0.05%) and quinalphos 25 EC (0.05%) were relatively more effective than thiamethoxam 25 WG (0.005%) and imidacloprid 70 WG (0.006%) in reducing the pest population, infestation and damage to plants. Deltamethrin 1% + triazophos 35 EC (1.0 mL L^{-1}) was the strongest resulting reduction in cutworm population by up to 92.7 percent, plant infestation by 97.2 percent and pretreatment plant damage by 88.5 percent, 14 days after first spray.

Other crops

Baxendale *et al*. (2001) [4] evaluated the selected pyrethroid insecticides (deltamethrin, lambda-cyhalothrin and bifenthrin) and a non-pyrethroid insecticide (chlorpyrifos) for residual control of black cutworm, *A. ipsilon* on creeping bent grass and found that all the treatments were provided cent percent reduction of black cutworm. A trial conducted by Scott-Dupree *et al*., (2008) [30] revealed that amongst different insecticides, chlorantraniliprole was found to be the most toxic insecticide against cutworm, *Peridroma saucia* (Hubner).

Conclusion

Cutworms are extremely polyphagous and target a wide variety of crops around the world including India. Many management practices are being followed for its management in areas having high infestation of cutworms. Other strategies, when used as single component for the mitigation of this species have not been found promising. Therefore, chemical control appears to be only the better feasible option to be incorporated in IPM for controlling this pest. Many workers have done laboratory as well as field studies for the evaluation of different groups of insecticides against *A. ipsilon* and suggested that some insecticides have a great potential to control this pest. Application of chemical insecticides is always associated with some negative impact on the lives and health of humans and animals: however, when used as intended and at doses declared by manufacturers, these substances could provide tremendous help in the control of cutworms. Insect resistance to insecticides is a growing concern, and it is important to note that insects are not immunized against particular chemical substances. By utilizing chemical control as a component of an integrated approach we can have better results in the fields. We can conclude that in near future the synergistic combinations of different insecticides with other control agents will provide a sustainable solution to the cutworm control.

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