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Plant Derived Pesticides in Control of Lepidopteran Insects: Dictum and Directions

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Abstract

Farm productivity is directly proportional to use of agrochemicals as observed from the first green revolution. Modern agriculture practices have been great promise for economic development of nation. Agriculture is the mainstay of Indian economy. Indian farmer is using wide ranges of chemical pesticides to limit the losses from diseases, in which insecticides account for 78%, 14% herbicides, 16% fungicides and others 4%. Chemical pesticide use is associated with risk and health hazards if not handled properly. Agriculture and agriculture allied sectors contribute nearly 26% of Gross Domestic Product of India, while about 60-80% of population depends on agriculture for livelihood. A majority of the population in India is engaged in agriculture and is therefore, exposed to the pesticides used in agriculture. Pesticides cause 14% of all occupational injuries in agriculture and 15% of fatal injuries. It is found that more than 70% of labourers used either “moderately hazardous” or “highly hazardous” pesticides as classified by WHO. However, 92% did not use any form of protection, while handling pesticides. Poverty and Illiteracy are greatly responsible for improper handling of pesticides.

Key Words: Castor, deltamethrin, India, pest, spanosad.
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Introduction

Insects are regarded as the most successful group within the Animal Kingdom, over 80 percent of all living beings are insects (Siva *et al.*, 2013). They are man’s chief competitors on earth and to some extent his benefactors. The unceasing struggle between man and his insect enemies started even before the dawn of civilization. In spite of the numerous advance made by man in evolving newer and deadlier weapons to fight the war against insects, he has not succeeded in controlling the thousands of serious pests which damages his food and other agricultural products (Mamgain *et al.*, 2013), destroy his possessions and even attack himself and transmit diseases and also injure his domestic animals. Moreover, India is an agricultural land having different climatic conditions due to which, it is possible to grow every crop and attends an outstanding position in the world with respect to several agricultural products (Khan *et al.*, 2013). The speedy development of agriculture is vital in the progress of our country. Today, India ranks second worldwide in farm output. It has a large and diverse agriculture and is one of the world’s leading producers as well as a major consumer with an expanding population to feed (Gillespie and Kadiyala, 2012).

Every year India suffers a heavy loss through insect pest infestation both in field and storage (Mamgain *et al.*, 2013). A pest is an animal whose population often increases above a certain level of economic injury and its existence conflicts with human welfare, convenience and profits. It was suggested by Edward and Heath (1964) that the pest status is reached when there is a 5% loss in yield in a particular crop. When a loss in yield cross this 5% level and reaches certain proportions, the pest can be defined as an economic pest. For practical purposes there is an economic threshold which is regarded by Stern *et al.* (1959) as the population density at which control measures should be started to prevent an increasing pest population from reaching the economic injury level. Once it is established that an insect causing economic losses, it becomes necessary to control it. The seriousness of the attack is decided by the feeding efficiency, host plant relationship, nature of the injuries conflicted and the susceptibility of the plant to attack. Every year, one out of five tones production damaged by insects (Banerji, 1985). Therefore, for keeping the pests suppressed it is important to control the damages which are done by the insect pests.

Methods or Strategies of Prevention

In recent years there is a significant lowering in the losses caused by insects because of the awareness of farmers and increase in scientific knowledge. To control any pest it is essential to have a correct idea of the insect pest identification, its biology, distribution, food range,

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damaging stage, mode of damage and the nutritional ecology. The method chosen must be economical and free from creating any other problem immediately or in future, it should not harm the natural enemies of the pest and should be easy to operate and be readily available to an ordinary cultivator. The need to protect economically important crops from the ravage of phytophagus insects by ecologically acceptable methods has led to the development of alternate strategies for insect control using an array of targets (Von Keyserling *et al.,* 1985; Van Beek *et al.,* 1994).

The chemical method is practically layman's weapon for quick and easy use because small amount of chemicals are sufficient for the control of large number of insects. About 80,000 tons of pesticides are used in agriculture in India annually (Srinivasan, 1997). Although the use of insecticides is very effective but it is ecologically unsound and has many serious limitations, resulted in ecological hazards and it will be highly damageable or danger for environmental pollution, ecosystem and chances are brighter to develop resistance in insects. Pesticide resistance in agriculture was first notified in India in 1963 when a number of serious pests were reported to become resistant to D.D.T and H.C.H (two of the most commonly using pesticides during the 1960's and 1970's). Resistance in insect has mainly been caused by excessive, indiscriminate and injudicious use of pesticides (Jayaraj, 1989). Growing pesticide resistance has meant that a large proportion of agricultural production is lost by pests. According to some estimates, these losses amount to between 20-30% of total production (Mehrotra, 1989). The unscientific and indiscriminate use of plant protection chemicals has often been reported as the cause of many endemic incidence of pest attack and pest resurgence in agriculture (Warren, 1989). The disruption of balance between insect pest and their natural enemies due to improper pest management is a recurring phenomenon in agro-ecosystem (Roychowdhury *et al.*, 2013). The short term effects of pesticides on natural enemies may be manifested within a single season by resurgence of pests due to the reduction of natural enemy complex, while the long term, cumulative impact of pesticides can be more dangerous by creating an imbalance in the ecosystem and periodic uncontrollable outbreaks (Meyerdirk *et al*., 1979).

The widely used method for the control of a pest is through different insecticides or through bio-pesticides. The problems caused by synthetic pesticides and their residues have increased the need for effective, bio-degradable insecticides with greater selectivity. It is clear that the excessive use of insecticides in agriculture is a serious cause of concern, therefore, use of bio-pesticides considered as safer substitute (Rathi and Gopalakrishnan, 2006). Though the effectiveness of bio-pesticides is not as comparable to that of synthetic pesticides, use of such preparations is advantageous considering the beneficial effects of such products. Many of the growers are using different types of preparations based on plants and other organic substances, which are known to have insecticidal properties. Most of the plants used in the preparations are locally available and hence farmers will be able to prepare the formulations themselves and apply to the plants. Many plants, microbes and their secondary metabolites are known to have various insecticidal properties against different species of insect. The plant products that are traditionally used and produced by the farmers in developing countries appear to be safe and promising (Jilani and Su, 1983).

The chemical groups, conventionally in use today are synthetic pyrethroids, organophosphates and carbamates. Pyrethroid insecticides are generally most effective and more stable than organophosphates (Casida, 1980). They are characterised by high knockdown and lethal activity, a wide spectrum, good residual activity, together with repellent and anti-feeding activity. With these characteristics, pyrethroid insecticides have become widely used for plant protection. Their major use has been for the control of bollworms and leafworms in cotton but they have also achieved widespread use for controlling various species of lepidopterous pests in fruits and vegetables, aphids in cereals, and many other minor outlets. They are also used in animal health and public health capacities. Although the early synthetic pyrethroids suffered from a lack of activity against mites and soil pests, later additions, such as fenpropathrin, have combined high acaricidal activity with insecticidal activity and further pyrethroids are being introduced for use in soil. The extent of pyrethroid use has increased progressively since the first of the 'photostable' pyrethroids was registered in 1974. In 1986, the market share of pyrethroids reached 25% of the total insecticide market for plant protection; this figure can be increased in the future (Hirano, 2006).

Pesticides in India

The promotion of High Yielding Varieties that marked the green revolution has led to large scale use of chemicals as pesticides. Increase in the use of chemicals as pesticides can result in various health and environmental problems like pesticides poisoning of farmers and farm workers, cardiopulmonary, neurological and skin disorders, fetal deformities, miscarriages, lowering the sperm count of applicators, etc. (Abhilash and Singh, 2009). Indian pesticide industry is the fourth largest in the world. Of the total market, around 75 percent is accounted by insecticides. At present, India is the largest producer of pesticides in Asia and ranks twelfth in the world for the use of pesticides with an annual production of 90,000 tonnes (Chitra *et al*., 2006). According to Mr. Pradeep Dave, President, PMFAI, and Chairman and Managing Director, Aimco Pesticides Ltd., "Pesticides consumption in India is low, less than 800 gm per acre against 16 kg per acre in the U.S. We want the government machinery to educate farmer sabout the use of pesticides through scientific programmes. All over the world better crop protection is used and here the government discourages the use of pesticides (Rosenberg, 2004). Over the past decade, high prices of HYV cotton crops encouraged tens of thousands of small and marginal farmers in the region to shift from traditional food crops to cotton. Shift to the cotton meant costly investments in seeds, fertilisers and pesticides which were possible for the small peasants of Telangana only through loans typically secured with their land or the gold ornaments of their wives. Now, in thousands of homes, dreams lie shattered amidst the ruin of thousands of families. A pall of despair and shock lies over the region today, where at least 180 debt ridden cotton farmers committed suicide in a short spell of just three months (Katti, 2012). The food we eat today contains a concoction of banned and restricted chemicals like DDT, benzene hex chloride (BHC), aldrin, dieldrin, lindane and many others that result in functional disorder and disease. It all began with the Green Revolution, which saw indiscriminate use of chemical fertilisers and pesticides. It left behind enormous toxic loads of contaminants in the environment, which eventually found their way into humans through the food chain (Reilly, 2008).

Impact of Pesticides

The impact of synthetic pesticides on beneficial arthropods and the human health risks by exposure to these chemicals are issues of growing concerns. This has prompted the development of new compounds, an example is Spinosad. Spinosad (Dow Agrosciences), a mixture of spinosyns A and D that are tetracyclic, macrocyclic compounds produced by actinomycete *Saccharopolyspora spinosa*. Spinosad, on the other hand, is a bacterial waste product produced by fermentation on a nutrient food source used by the one particular bacterium (*Saccharopolyspora spinosa*). As these products are created biosynthetically, it has been classified as, an organic substance by the USDA National Organic Standards Board (Racke, 2007). It is also OMRI Listed for use in organic production. Until Spinosad (pronounced spin-OH-sid) was discovered, one of the only organically acceptable insecticides was Bt (*Bacillus thuringensis*). Spinosad acts as a stomach and contact poison and degrades rapidly in the environment (Cisneros *et al.,* 2002). Sunlight and soil microbes break it down into carbon, hydrogen, oxygen and nitrogen. It has little toxicity to birds and mammals (Breslin *et al.,* 2000). It can be used on outdoor ornamentals, lawns, vegetables and fruit trees, to control caterpillars, thrips, leafminers, borers, fruit flies, spidermites, aphids, and more. It is effective as a protectant of stored grains (Fang *et al.,* 2002; Subramanyam *et al.,* 2006) and as a residual application to flooring surfaces.

Castor (*Ricinus communis*) is an important crop grown in tropical and sub-tropical regions of the world. Castor cake is used in agriculture as organic manure due to its high nitrogen content. The world castor seed production has fluctuated from a low of 937,000 tones to a high of 1,488,000 tones. India is the world's largest producer of castor seed and dominates the international castor oil trade. It contributes about 62 percent of the world production and ranks first (Sahadevan, 2002). The top producer of castor seed in India is Gujrat, with 86 percent share, followed by Rajasthan and Andhra Pradesh. Among the several factors that contribute to low productivity of castor, the insect pests constitute the major factor. Crop suffers heavily due to attack of various pests, which reduces their yield.

Castor hairy or tussock caterpillar, *Euproctis lunata* (Walk.) is a very destructive pest of castor belonging to order lepidoptera, family lymantridae. It is a leaf feeding insects and has a wide host range such as castor, cashew, cotton, guava, pomegranate, groundnut, linseed, grapevine etc. In India it is particularly found in Uttar Pradesh, Orissa, Punjab, Haryana, Madhya Pradesh, Andhra Pradesh, Karnatka and Tamil Nadu. The pest is active throughout the year but its speed of development is considerably reduced during winter. Moths emerged in the month of February and laid large number of eggs in clusters on the underside of the leaves. It has public health significance due to the urticating hairs of its larvae, which can cause severe rashes and irritation on skin and eyes called as Utricaria or skin dermatitis (Danthanarayana, 1983). The adult moths are pale yellow small sized. The life-cycle from egg to adult is stated to last 90-96 days (Vyas and Bohra, 1970). Body and eggs are covered with tufts of brown short hairs. They hatch in 5-7 days and the young larvae feed gregariously for the first few days. There are six larval instars.

Oriental leaf worm moth *Spodoptera litura* is a Noctuid moth which is considered as a serious but sporadic agricultural insect pest causes economic losses of crops from 25.8-100 percent based on crop stage and its infestation level in the field. It is also known as the Cluster caterpillar, Cotton leafworm, Tobacco cutworm, and Tropical armyworm. It is one of the most economically important insect pests in many countries including India, Japan, China, and other countries of Southeast Asia. It is also established on most Polynesian islands where it occurs in a variety of island forms. It infests a wide range of cultivated food plants numbering around 112, belonging to 44 families of which 40 species are known from India (Sahayaraj and Sathyamoorthi, 2010). It has a large host range of more than 150 host plants from over 40 mostly dicotyledonous plant families including crops, vegetables, weeds and ornamental plants. It feeds gregariously on leaves leaving midrib veins only. It is a major pest of many crops.

Survey of Literature Concerned

More than half of the world's known animal species are insects (May, 1992) in which lepidoptera is the 2nd largest and the most diverse order in the class insecta (Benton, 1995). Upto now more than 100,000 species of lepidopterous insects have been studied (Richards and Davies, 1977), most of them are phytophagous and polyphagous. They are the greatest enemies of the agriculture crops and act as serious pests. The economic importance of the lepidoptera arises almost entirely from the activities of the larvae. They have chewing-type mouthparts and are among the world's greatest pests (Price *et al.,* 1996).

Bhanukiran *et al.* (1997) investigated the efficacy of two conventional insecticides, *viz*, methomyl and triazophos either alone or in combination with biopesticide diflubenzuron against *Spodoptera litura* and reported that 4 time spraying of crop with 0.05% methomyl and 0.05% triazophos alone gave 45.20% and 43.32%, respectively, overall larval population reduction over control, whereas the combination of methomyl (0.025%) with diflubenzuron (0.0125%) proved to be the most effective and gave 53.23% reduction in larval population over control followed by triazophos (0.025 percent) + diflubenzuron (0.0125%) that gave 50.38 percent reduction in population. The combinations of these two conventionally used insecticides with each of NPV 125 LE/ha and *neem* oil 0.5% were relatively less effective against *S. litura*.

Singh *et al.* (1987) studied the comparative toxicity of various pyrethroids like cypermethrin A, cypermethrin B, decamethrin [deltamethrin] and fanvalerate on hairy andnon-hairy caterpillars such as *Spodoptera litura*, *Achaea janata*, *Euproctis lunata* and *Diacrisia obliqua* and concluded that cypermethrin was most toxic to *Euproctis lunata*. Moreover, Karmarkar *et al*. (2002) also made observation on the comparative toxicity of some neem products like neem oil, Nimbecidene and Nimbitor against *S. litura* and reported that the 2nd instar larvae treatment with 2 percent Nimbecidene, 2 percent Neemark and 2 percent Nimbitor persisted for five days, whereas fourth instar larvae treated with 2 percent neem oil, 1 percent Nimbecidine, 2 percent Nimbecidene and 2 percent Nimbitor persisted for four days after application.

Laboratory experiments were conducted by Elliott *et al*. (2007) to evaluate the contact and oral toxicity of commercial formulations of spinosad and deltamethrin to adults of the crucifer flea beetle, *Phyllotreta cruciferae* (Goeze). Method of exposure had a significant effect on flea beetle mortality and feeding damage to canola seedlings. Topical treatment of flea beetles with deltamethrin or different concentrations of spinosad resulted in significantly lower mortality and higher feeding damage than exposure to treated canola cotyledons. Results indicated that spinosad was more toxic by ingestion than by topical contact. Mortality from treated cotyledons was significantly higher with 60 ppm deltamethrin than with 80 or 120 ppm spinosad after 24 h exposure but not after 120 h exposure. Delayed mortality in the spinosad treatments did not result in high feeding damage; damage after 120 was not significantly different in the spinosad and deltamethrin treatments. Low concentrations of spinosad (40 ppm) strongly inhibited feeding activity within 24 h after exposure. Mortality from spinosad was higher after beetles were exposed to treated cotyledons for 120 h than for 24 h. Mortality from spinosad, but not deltamethrin, was significantly higher at 25 °C than at 15 °C. An ionic surfactant, polyethylenimine, increased the toxicity of 40 ppm spinosad. Our study suggests that spinosad has potential for use as an insecticide against crucifer flea beetles on canola.

Moreover, toxicity of emamectin benzoate, an avermectin semi synthetic lactic insecticide, was evaluated in laboratory to determine its performance on three different larval stages (5, 7 and 9 day old) on *Spodoptera litura.* Three different types of assay techniques are used viz. leaf dip, potter's tower and thin film, different formulation of emamectin benzoate were used which was compared with a conventional insecticide i.e. cypermethrin. Median lethal concentration (LC_{5o}) of the emamectin benzoate, 1.9 percent EC against 5 day, 7 day and 9 day larvae were recorded as 0.00005, 0.00017 and 0.0007 percent, respectively. Emulsifiable concentrates (EC, 1.9 and 5 percent) of emamectin benzoate outperformed the water-soluble granule (WSG, 5 percent) formulation, whereas, EC formulation of emamectin benzoate 1.9 percent EC found better than 5 percent EC. Amongst test-methods, leaf-dip bioassay was suitable and sensitive for the test-insecticide, obviously for the fact that, emamectin benzoate is a stomach poison is addition to its contact mode of action (Birah *et al*., 2008).

Furthermore, Ahmad *et al*. (2008) observed the toxicity of cypermethrin, deltamethrin, profenofos, chlorpyrifos and fipronil separately and in mixtures against laboratory susceptible *S. litura* and two field-collected populations. Cypermethrin, deltamethrin, chlorpyrifos and profenofos were significantly more resistant to field population from Khanewal (KWL) than one collected from Muzaffar Garh (MGH). Mixtures of cypermethrin + chlorpyrifos or profenofos and of deltamethrin + chlorpyrifos or profenofos at 1:1, 1:10 and 1:20 ratios significantly increased (P<0.01) toxicity to cypermethrin and deltamethrin in field populations. The combination indices of cypermethrin + chlorpyrifos at 1:1 and 1:10 ratios and cypermethrin+fipronil at 1:1, 1:10 and 1:20 ratios for the KWL strain and of cypermethrin+ profenofos or fipronil at 1:1, 1:10 and 1:20 ratios for MGH were significantly below 1, suggesting synergistic interactions. The study indicates that chlorpyrifos, profenofos and fipronil could be used in mixtures to restore cypermethrin and deltamethrin susceptibility.

Singh *et al.* (1985) determined the relative toxicity of some botanical insecticides viz., pyrethrins, rotenone and nicotine sulfate against a number of insect pests and compare their toxicity with several conventional insecticides and found that botanical insecticides were more effective against a number of insects including larvae of *E. lunata, M. persicae, B. brassicae* (Mamgain *et al.*, 2013)*, D. carthami and L. erysimi* and were relatively least effective against the predator *C. septempunctata.*

In addition, Rathod *et al*. (2003) determine the efficacy of imidacloprid against jassids (*Amrasca bigutulla*) aphids (*Aphis gossypi*), and thrips (*Thrips tabaci*) infesting cotton. The treatments comprised imidacloprid at 5, 7.5 and 10 g/kg, diafenthiuron 300 and 400 g/ha, and dimethoate at 1.25 liters/ha .The lowest mean population of jassids (0.99), aphids (4.41) and thrips (1.73) per 3 leaves were obtained with 10g imidacloprid/ha, 300g diafenthiuron/ha and 5g imidacloprid/ha respectively. The highest cotton yield (826 kg/ha) was obtained with 5g imidacloprid/ha.

Tripathi and Singh (2003) evaluated the bio-efficacy of *Bacillus thuringiensis* against larvae of *Spodoptera litura* at different age groups and reported that the early instars showed higher mortality as compared to later ones. Efficacy of diflubenzuron, azadirachtin, *Baeuveria bassiana*, spinosad, endosulfan, esfenvalerate and naled against third instar nymphs of *Melanopus defferentialis* (Thomas) at temperature ranging from 10 to 35 °C. In the lab, the treatment with fenvalerate resulted in 100 percent mortality at temperature of 10 to 35 °C and efficacy was not temp dependent. Treatment with spinosad resulted in similar mortality as with fenvalerate at all temperatures except 10 °C. The activity of *B. bassiana* was greatest at 25 °C and was adversely affected by high and low temp.

Nevertheless, an experiment was conducted to determine the efficacy and persistence of spinosad against *Rhyzopertha dominica* (Fab.) in wheat stored for 9 months at 30 ^{o}C temperature and 55-70 percent relative humidity. Spinosad applied at 0.5 or 1 mgkg-^{1} was completely effective for 9 months, with 100 percent adult mortality after 14 days of exposure and no live f_1 adults produced. Adult mortality was ≤100 percent in some samples of wheat treated with 0.1 $mgkg^{-1}$ of spinosad, and live progeny were produced in all samples treated at this level. The results showed that spinosad is likely to be an effective grain protectant against *R. dominica* in wheat stored in warm climates (Gregory *et al*., 2005).

Ovicidal effect of some pyrethroids are tested against *Earis vitella* on okra and *Spodopteralitura* and *Euproctis lunata* on castor (*Ricinus communis*) and observed that decamethrin [deltamethrin] was most effective against the eggs of *Earis vitella* followed by cypermethrin and permethrin (Singh and Sircar, 1986). In laboratory, bioassay studies on two age groups, neonate (0-24 hrs old) and 6 day old larvae of *Spodoptera litura* and 8 day old larvae of *Spilarctia obliqua* (Wlk.) was carried out by Kuldeep *et al.* (2004) to determine the effect of sublethal doses of lufenuron. Growth and development of both test insects was suppressed drastically. At 400 ppm it was highly effective and caused 100 percent mortality of both test insects at both age groups. However, larval period significantly increased at lower dose. Percent pupation and adult emergence were severely reduced. Further, 0-24 hrs old larvae were more susceptible than older one.

Besides this, the toxicity of spinosad and methoxyfenozide against neonates and fourth instars of *Spodoptera littoralis* (Boisduval) was tested by Pineda *et al*. (2006) under laboratory conditions. According to LC_{50} values, no significant differences were observed between spinosad (0.50 mg [AI]/kg diet) and methoxyfenozide (0.54 mg [AI]/kg diet) after 48 h of ingestion treatment on neonate larvae, based on the overlap of 95 percent CL. Similarly, on fourth instars, no significant differences were observed between LC_{50} (2.98 and 5.17 mg [AI]/kg diet for spinosad and methoxyfenozide, respectively, at 96 h after ingestion of artificial diet) and LD_{50} (4.74 and 2.68 µg [AI]/g larva for spinosad and methoxyfenozide, respectively, at 144 h after topical application). In addition, spinosad and methoxyfenozide significantly suppressed weight gain of neonates and fourth instars if continuously fed with artificial diet containing the insecticides. They conclude that spinosad and methoxyfenozide represent an important choice to be used in integrated pest management where *S. littoralis* is a major pest.

Kumar and Srivastava (2008) studied the effect of some pyrethroids viz., alphamethrin, cypermethrin, deltamethrin, lambdacyhalothrin and dimethoate under laboratory conditions at 0.3 and 0.01 percent concentration on 8 days old larvae of tobacco caterpillar *Spodoptera litura* fed with treated leaf discs continuously for 2 days. The foliar treatment with sublethal doses of these insecticides caused a significant reduction in feeding and larval weight at 2DAF over control. Synthetic pyrethroids at higher concentration resulted in a significant negative weight gain (= wt. loss) whereas with lower concentration nominal weight gain was observed. Alphamethrin, cypermethrin, deltamethrin at 0.3 percent reduce the pupal weight by approximately 50-60 percent, whereas lambda-cyhalothrin and dimethoate by 38 and 15 percent respectively. Alphamethrin at 0.3 percent reduce the pupation by 57.1 percent. The adult emergence significantly reduced 50-60 percent at 0.3 percent and 22-30 percent at 0.01 percent by SPs in comparison of untreated control. No mortality was observed in dimethoate at 0.3 percent and in control.

On other hand, Sharma *et al.* (2008) studied the effect of selection pressure of endosulfan, deltamethrin and cypermethrin on the duration and morphometrics of diamond black moth, *Plutella xylostella* (L.) and observed that these insecticides adversely affected the dimension of different developmental stages. The size of the adults of selected strains was significantly less than that of parent generation and non-selected strain. The longevity of male and female as well as incubation period also get affected and become shorter than the parent generation and those individuals reared under no selection pressure.

The effect of enzyme inhibitors piperonyl butoxide (PBO) and tribufos (DEF) was studied in combination with insecticides profenofos, methomyl, thiodicarb, cypermethrin, λ-cyhalothrin, bifenthrin, indoxacarb, and spinosad in the resistant Pakistani populations of *S.litura* using a leaf-dip bioassay. Both the inhibitors synergised carbamates methomyl and thiodicarb but showed no synergistic effect on an organophosphate profenofos. These inhibitors produced a synergism with cypermethrin but had no synergism with bifenthrin. PBO and DEF enhanced the toxicity of λ-cyhalothrin and indoxacarb in one population but not in the other. Spinosad was synergised by DEF but not by PBO. The potent synergism of carbamates, pyrethroids, indoxacarb and spinosad by PBO and DEF indicates that detoxification by cytochrome P450 monooxygenases and esterases is at least partially involved in imparting resistance to these insecticides in *S.litura*. However, a limited synergism of insecticides shown by both the synergists implies that other mechanisms such as target site insensitivity and reduced cuticular penetration may be more important mechanisms of resistance in the Pakistani populations of *S. litura (*Ahmad, 2009).

Comparative toxicity of bio-insecticide i.e. spinosad 45SC along with six conventionally used chemical insecticides viz., emamectin benzoate 5WSG, cypermethrin 10 EC, quinalphos 25 EC, endosulfan 35 EC, Lambda cyhalothrin 5 EC, Chlorpyrifos 20 EC against shoot and fruit borer (*Leucinodes orbonalis*), leafhopper (*Amrasca biguttula* biguttula), whitefly (*Bemisia tabaci*), lace bug (*Urentius* hystericellus), meal bug (*Phenacoccus* solenopsis) and hadda beetle (*Henosepilachna vigintioctopunctata* and *Epilachna dodecastigma*) and also against some natural enemies (*Encarsia lutea, Chrysoperla carnea* and ladybird beetle) on eggplant and reported that spinosad @162.5 ml/h was most effective against shoot and fruit borer getting the maximum fruit yield and highest cost benefit ratio but not effective against sucking pest and hudda beetle and was safe to natural enemies whereas the chemical insecticides proved toxic to all of them (Kaul *et al*., 2009).

Kodandaram and Dhingra (2005) studied the relative potency of ten combination insecticides along with their respective individual insecticides by direct spray and leaf dip method against third instar larvae of *Spodoptera litura* and reported that irrespective of method of application Ducord and alphacypermethrin; Koranda and acephate; Virat and quinalphos are equally potent to each other, whereas Polytrin C and cypermethrin; Virat and cypermethrin; Nagata and cypermethrin; Koranda and fenvalerate exhibited same potency when applied by leaf dip method. Only Bulldockstar and betacyfluthrin, exhibited similar potency when tested by direct spray. Further, they concluded that the data on the susceptibility of *S.litura* serve as a ready reckoner for selection of the combination products, in various pest management programmes.

Singh and Singh (1997) studied the relative susceptibility of six synthetic pyrethroids (lambdacyhalothrin, decamethrin, cypermethrin., bifenthrin, bulldock, fenvalerate) and four non-pyrethroids (chlorpyriphos, malathion, endosulfan and lindane) against second instar larvae of *Spodoptera litura* by bioassay method under laboratory conditions and recorded that lambdacyhalothrin was highly effective whereas lindane was least effective. Based on the LC_{50} values, the order of toxicity of different insecticides was: lambdacyhalothrin > decamethrin > cypermethrin > bifenthrin > bulldock > chlorpyriphos > fenvalerate > malathion > endosulfan > lindane. Ahmad *et al*. (2005) studied the effectiveness of some new chemistry insecticides against 2nd instar larvae of leaf worm, *Spodoptera litura* under controlled laboratory conditions for time-oriented mortality at three different concentration values closer to their LC_{50}s and observed that emamectin proved to be the best followed by lufenuron, spinosad and indoxacarb, respectively, whereas abamectin proved to be the least effective to control this pest.

Further, to determine time trends in mortality for various insecticides (Ahmad *et al*., 2006) which are being used against cotton pests, the fourth instar larvae of *Spodoptera litura* was collected from Muzaffar Garh and tested for pyrethroids, organophosphate and new chemistry insecticides. The efficacy of the insecticides was examined by time-oriented mortality at LC_{50}, through leaf-dip bioassays in the laboratory. In sodium channel agonists, endosulfan was the most efficient insecticide. The cholinesterase inhibitors tested, chlorpyrifos showed high efficiency while phoxim performed better in time-oriented mortality. Emamectin benzoate proved to be the most efficient insecticide in new chemistry insecticides tested. Spinosad and indoxacarb had almost similar LC_{50} and LT_{50} values. The least effective insecticide found was abamectin. The results are discussed in relation to Integrated Pest Management (IPM).

Suby *et al.* (2008) investigated certain newer insecticides with novel mode of action along with some conventional insecticides by using 'leaf dip' method against 4, 7 and 10 day old larvae of *Spodoptera litura* and reported that emamectin benzoate 5 percent WSG was the most effective and abamecytin 1.9 percent EC the least among the insecticides tested even though both belong to avermectin benzoate. The older of relative toxicity shows that emamectin benzoate is 500 to 1200 times toxic to cypermethrin across the larval stages.

Boreddy *et al*. (2000) used the petroleum ether extract of *Annona* seed against IV instar larvae of *S. litura* and calculated the LC_{50} value. Antifedant activity of Azadirachtin (Neemazal T/S) and diflubenuron (Dimilin 25% WP) against *Spodoptera litura* by taking 7 concentration of neemazal viz; 0.3, 1.5, 3, 15, 30,150, 300 ppm and of Dimilin viz; 50, 100, 250, 500, 1000 and 2000 ppm respectively and observed that Neemzal 300 and 150 ppm had more feeding deterrent effect than control while in case of Dimilin 2000 and 1000 ppm had more feeding deterrent effect.

Extracts of aerial parts of *Andrographis paniculata* were prepared by Pathrose *et al.* (2007) in hexane and methanol and were applied topically on the dorsum of 7-day old larvae of *Spodoptera litura.* Larval and pupal weight reduction was highest with methanol extract. Larval-pupal intermediates could be observed with both the extracts while abnormal adults were formed with methanol extract only.

Similarly, Sabitha and Suryanarayna (2009) tested various concentrations of flower head extract of *Spilanthes acmella* for the antifeedant activity against third instar larvae of *Spodoptera litura* and reported that among different concentrations 2.5 percent was the most effective and produced 100 percent feeding deterrence followed by 2.0 percent that shows 96.3 percent deterrence, 1.5 percent (81.0 percent) and 1.0 percent which caused 66.6 percent deterrence in feeding. The other concentrations were less effective and show 20.1 and 30.8 percent feeding deterrence.

Moreover, in Nayak *et al*. (2005) carried out laboratory experiments on eight relevant resistant strains of storage pests (four beetle and four psocid species) to determine the potential of the bacterium-derived insecticide, spinosad as a new grain protectant. Adult insects of each strain were exposed to untreated wheat (control) and wheat treated with spinosad at 0.1, 0.5 and 1 mg [a.i.]/kg of grain. Among beetles, spinosad was most effective against *Rhyzopertha dominica* (F.), with 100 percent adult mortality and progeny reduction after 14 d exposure at 1 mg [a.i.]/kg, whereas its efficacy was less with *Sitophilus oryzae* (L.), and least with *Tribolium castaneum* (Herbst) and *Oryzaephilus surinamensis* (L.). Against the psocids, spinosad was most effective against *Liposcelis entomophila* (Enderlein), with 100 percent adult mortality after 28 d exposure at 1 mg [a.i.]/kg and 92 percent progeny reduction after 14 d exposure and 100 percent subsequently. Spinosad was only moderately effective against *Liposcelis bostrychophila* Badonnel, *L. decolor* (Pearman) and *L. paeta* Pearman. Spinosad to be a potential protectant against *R. dominica* and *L. entomophila* in stored grain in Australia. This potential use would be in combination with another protectant capable of controlling other members of the pest complex.

Furthermore, Dhingra *et al.* (2006) made observations on comparative toxicity of neem oil micro and macro-emulsion and reported that neem oil micro-emulsion showed a significantly superior bio-efficacy than its macro-emulsion against *Spodoptera litura, Spilarctia obliqua* and *Euproctis lunata.* The Lc_{50} values for inhibiting adult emergence in case of micro- and macro-emulsions were 0.09 and 0.14 percent against *S. litura*; 0.07 and 0.10 percent against *S. obliqua* and 0.05 and 0.02 percent against *E. lunata.* The relative effectiveness of micro- to macro- was 1.5:1.0 against *S. litura;* 1.4: 1.0 against S. *obliqua* and 3.9:1 against *E. lunata.*

Mogal *et al.* (1980) studied the relative toxicity of 11 insecticides in the laboratory against the larvae of *Euproctis subnotata* (Wlk.) collected from the field and concluded that malathion at about 0.1 percent and carbaryl at about 0.2 percent could be recommended for practical control of the pest; a single application to the ears is sufficient, since oviposition takes place after flowering and only 1 generation of any size has time to develop before the ears become too hard.

A comparative study on the relative toxicity of seven synthetic pyrethroids against Tussock caterpillar*, Euproctis lunata* (walk) under laboratory conditions was done by Dhingra *et al*. (2005). On the basis of LC_{50} values, lambdacyhalothrin, beta-cyfluthrin, alpha-cypermethrin, fenvalerate, deltamethrin and cypermethrin were 28.03, 14.44, 7.91, 2.37, 1.98 and 1.60 times, respectively, as toxic as fenpropathrin. A comparison of Lc_{50} values of cypermethrin, fenvalerate and deltamethrin determined during the last one and a half decade (1987-2002) revealed a pronounced shift in the susceptibility level of *E. lunata*. Within a span of 15 years, there was 10.76, 8.9 and 8.3 times increase in the LC_{50} values of cypermethrin, fenvalerate and deltamethrin, respectively, against *E. lunata*. Similarly, the observation on the relative resistance of hairy and non-hairy larvae to pyrethroids shows that *S. litura* was relatively more resistant to all the 7 pyrethroids compared to *S. oblique, A. janata* and *E. lunata.* Thus the toxicity of pyrethroids to various pests varied considerably from one insect to another.

Rahman and Chaudhary (1987) studied the efficacy of Alsystin (triflumuron), Dimilin (Diflubenzuron) and bactospeine (*B. thuringiensis*) against babul defoliator, *Euproctis lunata* walk and observed varied degree of mortality at various concentrations. On the basis of the results they recommended that triflumuron and diflubenzuron at 0.04 percent be used in nurseries and young plantations for control of *Euproctis lunata*.

Efficacy of Spanosad and Deltamethrin

Insecticides are often the only effective remedy for quickly and inexpensively reducing the pest population below the economic injury levels. If in anyway crop is being damaged by pest attack, we must have to prevent it from damage by using the appropriate methods. The use of toxic chemicals and bio-pesticides for the control of pest increases tremendously during the last few decades. The toxicity of insecticides to humans and wildlife has caused much public concern and prompted the use of more target-specific chemicals. This approach has led to the development of botanical such as citrus oil, derivatives, neem-azadirachtin etc., soaps and oils, microbial insecticides such as *Beauveria*, *Bacillus thruingensis*, pheromones, and natural products like spinosads, nitenpyram, imidacloprid etc, which are able to efficiently control agricultural pest species with minimum effects of natural enemies. Spinosad is a mixture of spinosyn A and D which are tetracyclic-macrolide secondary metabolites produced by anactinomycete, *Saccharopolyspora spinosa* (Mertz and Yao, 1990; Thompson *et al*., 1997). This compound has two unique modes of action, acting primarily on the insect nervous system at the nicotinic acetylcholine receptor and exhibiting activity at GABA receptor (Salgado, 1997: Watson, 2001). It is a broad spectrum natural bio-insecticide offered a new mode of action and relatively safe on natural enemies (Temerak, 2003). Sarfraz *et al.* (2005) reported that currently there are only a few cases of insect resistance to spinosad and it is not known to share cross-resistance mechanisms with any existing class of insecticide. On the basis of simple reciprocal crosses and backcrosses, resistance appears to be inherited as a co-dominant trait controlled by a single locus. Furthermore, they concluded that in general, spinosad has larger margins of safety for parasitoids and predators but its higher concentrations may prove lethal to certain beneficial arthropods. The efficacy of spinosad can be conserved if it is judiciously rotated with other suitable insecticides in a spray program and the maximum number of applications is restricted. Thus, it becomes inevitable to find out the most effective chemicals against particular species of insect pest which do not adversely affect the environment and are also bio-degradable.

Conclusion and Future Recommendations

On the basis of the present findings it is concluded that the application of the insecticides and pesticides causes not only heavy mortality but also developed in fecundity and infertility in the affected females, thus keep the pest population at the minimum. The recommended concentrations may be regarded as safe for spray operator because the application of high concentrations put the spray operator at greater risk, lead to residue hazards or prove uneconomic.

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