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Heliothis/Helicoverpa Management: Emerging Trends and Prospects for Future Research

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Heliothis/Helicoverpa—The global problem

The cotton bollworm/corn earworm/legume pod borer (*Heliothis/Helicoverpa*) are the most important constraints to increase the production and productivity of crops worldwide (Hardwick 1970; Fitt 1989). These pests damage a wide range of economically important crops including cotton, chickpea, pigeonpea, maize, peas, cowpea, sunflower, sorghum, groundnut, field beans, tobacco, a range of vegetables, fruit crops and tree species. Of these, *Helicoverpa armigera* (Hübner) is widely distributed across Asia, Africa, Australia and the Mediterranean Europe; while *H. punctigera* (Wallengren) is native to Australia. *Helicoverpa zea* (Boddie) and *H. virescens* (Fabricius) are important pests in the American continent. *Heliothis/Helicoverpa* species cause an estimated loss of US$5 billion annually, despite the fact that pesticides costing over US$1 billion are used to control them on different crops. This figure does not take into account the cost of harmful effects of insecticides on the non-target organisms and the environment. In fact, more than 50% of the pesticides produced worldwide are used to control Heliothine pests, and yet, they still cause

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widespread damage to crops, ranging between 25% damage to complete failure of crops (Sharma 2001).

Crop production in many countries, especially in the semi-arid tropics (SAT), is severely threatened by the increasing difficulties in controlling the damage caused by these pests. This problem has further been exacerbated by the dramatic increase in levels of resistance in *Heliothis/Helicoverpa* populations to the commonly used insecticides, and therefore, there is a need to incorporate strategies that do not depend solely on insecticides. There is an urgent need to adopt integrated pest management strategies to reduce the negative effects of chemical pesticides. An effort was made in this book to take a critical look at the available information to formulate a strategy for utilization of different components of *Heliothis/Helicoverpa* management to minimize the extent of losses due to these pests, and identify the gaps in our knowledge for future research thrusts.

Bio-ecology and pest forecasting

Replacement of landrace cultivars has led to considerable erosion of genetic diversity. As a result, there is a paradigm shift in host plant – insect herbivore interactions and their relative abundance. Some of the present day pest problems are the result of large-scale monocultures, and heavy application of fertilizers and pesticides. There is a need to approach *Heliothis/Helicoverpa* management with a focus on habitat management. However, while increasing diversity will lead to greater stability in populations of herbivores and their natural enemies, the question is whether we can afford to go thousands of years back, and what can we do with the mess that may be created by such an approach? This is still an unresolved issue. The question, whether there are different biotypes of this species or just genetic variation in terms of different color morphs, host specificity and resistance to insecticides; which possibly represents co-evolution of insects and the crops, needs thorough investigation. Similarly, the role of aestivation in synchronous appearance of *Heliothis/Helicoverpa* populations needs to be properly understood. During the International Workshop on *Heliothis* management in 1981 at ICRISAT (Reed and Kumble 1982), it was concluded that, "**there are differences between *Helicoverpa* populations from different areas that merit race or sub-specific rank**". Twenty years later, this statement still needs to be substantiated.

Heliothis/Helicoverpa incidence and extent of losses in different crops has changed dramatically over the past five decades. In the fifties, *Helicoverpa* was not considered to be a pest of cotton in India, but by the mid-seventies, it became a major pest, displacing pink bollworm and spotted bollworm as the major pests of this crop. One of the reasons for this change had been the development of hairy varieties of cotton for resistance to jassids, which are preferred by *Helicoverpa* for oviposition. This also coincided with the release of interspecific hybrids of cotton such as Varalakshmi and Jayadhar in India.

During the 1981 *Heliothis* workshop, it was recommended that, **"We should try to determine not only if, when and how much migration occurs, but why it occurs"**. *Heliothis/Helicoverpa* movement from one crop to another and from one region to another, and the factors that trigger such movements are still not properly understood. Early warning or pest-forecasting is very important, especially for targeting the control measures against the young larval instars. Studies on spatial and temporal changes in population dynamics are needed to devise appropriate control measures. There is a need to study migration patterns and local fluctuations in *Heliothis/Helicoverpa* abundance as several crops serve as collateral and alternate hosts for these pests. Pheromone traps have been used for monitoring pest populations, but their value in predicting the onset of pest infestations, and peak periods of activity need to be properly understood. Information on population monitoring in India has indicated that in the Deccan Peninsula; high rainfall in June–September, and low rainfall in November results in low incidence, while low rainfall in June–September, and high rainfall in November results in high incidence. Farmers' knowledge for forecasting pest incidence can also be used to predict pest incidence, e.g., in South India, low morning temperature and heavy dew lead to high pest incidence. The polyphagous nature of these pests, wide geographical range, and a large number of natural enemies make population modeling and forecasting a difficult task.

Forecasting systems have been developed for different species in different crops and regions. However, most of these systems can at best predict the onset of infestation, but are rarely accurate enough to predict heavy pest incidence. At times, adults settle on a crop, after long distance migration, where there were no insects earlier. The population developing in a crop or a region might migrate away to another crop or region. There is a need to understand host plant—insect—environment interactions in different regions to be able to develop appropriate strategies for integrated management of these pests. There is also a need to understand the key biotic/abiotic mortality factors at different locations in different crops, at different life stages and the mortality regulated by the host plant. There is a need for information on co-evolutionary trends, sustainability of the ecosystem and homeostasis in *Heliothis/Helicoverpa* populations so as to be able to develop integrated biotic stress management as a means of minimizing the extent of losses due to these pests. There is a need to develop forecasting system based on:

- Surviellance.
- Life tables and key mortality factors.
- Bio-ecology in relation to crop phenology.
- Population dynamics across seasons and locations.

Host plant resistance

Host plant resistance (HPR) can play a major role in integrated management of *Heliothis/Helicoverpa*. Currently available cultivars with resistance to these pests have the potential to reduce the number of sprays by one-third to half. HPR can also be deployed in combination with biological, cultural and chemical control methods. Absolute control through host plant resistance, however, is not the focus of current research effort on breeding for resistance to these pests. However, a combination of HPR with judicious application of pesticides and other methods of pest control is expected to be quite effective in integrated management of these pests. There is a need to capitalize on the tolerance mechanism of resistance exhibited by several economically important crops such as cotton, pigeonpea and chickpea that serve as a host to *Heliothis/Helicoverpa*.

The need to standardize resistance-screening techniques was emphasized during the 1981 workshop on *Heliothis*. While some progress has been made in cereals, chickpea and cotton, much remains to be done in case of pigeonpea and many other crops. Host plant resistance is one of the cheapest and potentially most effective tool for reducing damage by *Heliothis/Helicoverpa*. Efforts to develop cultivars resistant to these pests have been on going for the last two decades. However, breeding for resistance to these pests has not been as successful as for resistance to plant diseases or other insects due to the low-level of resistance available in the cultivated species, and the complexity of interactions between the insects and their host plants. However, high levels of resistance have been identified in the wild relatives of cotton, chickpea and pigeonpea, which can be used in crop improvement through wide hybridization, genetic transformation, or marker-assisted selection. Resistance genes from the wild relatives can also be used to increase the levels and diversify the genetic basis of resistance to these insects.

Breeding for resistance to insect pests results in a net return of $300 per $1 of investment in research. There is a need to understand the insect—host—environment interactions, mechanisms of resistance, nature and number of genes involved, and inheritance of resistance for developing appropriate strategies to breed for resistance to these pests. Plant breeders can focus on a number of physico-chemical characteristics as markers, and also there is a need to know the followup value of different resistance mechanisms to develop appropriate strategies to breed for resistance to these pests. There is an urgent need to educate the general public about the potential benefits for using even low levels of resistance in pest management, as these can result in a substantial reduction in pesticide use. There is also a need to understand the interactions between the insect-resistant cultivars and the natural enemies of these pests to develop crop cultivars that are more hospitable to the natural enemies. This may have the same effect an crop pests as developing cultivars with resistance to the target insect pests. Interdisciplinary and inter-institutional collaboration, including the private seed sector is crucial to realize the benefits of host plant resistance in the management of *Heliothis/Helicoverpa* in different crops. There is a need to focus future research on:

- Screening and selection criteria for resistance to *Heliothis/Helicoverpa.*
- Mechanisms and inheritance of resistance for gene pyramiding to increase the durability of resistance – two mechanisms are better than one.
- Introgression of diverse resistance genes from closely related wild relatives of the crops.
- Develop crop cultivars that are compatible or more hospitable to the natural enemies.
- Combining resistance to *Heliothis/Helicoverpa* with resistance to other biotic and abiotic stress factors.
- Develop an understanding of the compatibility of HPR with other components of pest management – impaired insect development as a result of host plant resistance will increase the effectiveness of chemical insecticides and bio-control agents.
- Giving same weightage to plant resistance as to crop yield while identifying cultivars for use by the farmers.

Application of modern tools of biotechnology to improve HPR

Genetic transformation and marker-assisted selection have enabled transfer of genes from the same and / or unrelated species to the target species. Several studies with transformed plants have shown the promise of this technology in pest management, including *Heliothis / Helicoverpa*. Genetically transformed cotton and maize cultivars with genes from *Bacillus thuringiensis* (*Bt*) have been deployed for large-scale cultivation in USA, Australia, Brazil, China, Canada, South Africa and India to minimize the losses due to these pests, and also to reduce the amounts of pesticides used. Transgenic chickpea, pigeonpea, soybean and groundnut with *Bt* genes for resistance to *Heliothis / Helicoverpa* have also been developed, which need to be tested in the field for their efficacy and bio-safety, before deployment in the field. However, there are serious concerns about the bio-safety aspects of transgenics in some countries, and these issues need to be addressed by scientists before the genetically transformed plants are accepted globally for *Heliothis/Helicoverpa* management. Alternative molecules such as plant protease inhibitors (soybean trypsin inhibitor, cowpea trypsin inhibitor and plant lectins), alpha amylase inhibitors, neuropeptides and secondary plant metabolites may also be considered as candidate genes for genetic transformation of crops for resistance to *Heliothis / Helicoverpa* either alone or in combination with *Bt* toxins. Protease inhibitors from the non-host plants can be used effectively for genetic transformation of crops for resistance to these insects.

Concerns have also been expressed about the development of resistance in *Heliothis/Helicoverpa* populations to *Bt* toxins. Information has been generated for some regions/crops on: i) geographic and temporal variation in susceptibility of *Heliothis/Helicoverpa* populations to *Bt*, ii) development of resistance under selection pressure, iii) cross resistance to various toxins and insecticides, and iv) frequency of resistance genes and genetics of resistance. There is a need to study insect behavior in relation to resistance development, and develop long-term strategies for resistance management. Management of resistance to *Bt* in *Heliothis/Helicoverpa* should involve:

- High dose, refugia (largely in monocultures) and gene pyramiding.
- Stable expression of the transgene.
- Rotating *Bt* crops with non-*Bt* crops.
- Expression of the transgene in plant parts where the insects feed.
- Biosafety assessment of the transgenes before deployment on farmers' fields.
- Monitoring development of resistance and integrated pest management.

Marker assisted breeding for resistance to *Heliothis / Helicoverpa* also holds a promise for developing crops with resistance to these pests. Some beginning has been made in this regard in cotton, chickpea and soybean, but genetic linkage maps of other principal hosts still need to be developed. Marker-assisted selection also has a great potential for developing biotype specific resistance, and other specific applications.

Biological control

During the proceedings of the 1981 *Heliothis* workshop, it was concluded that **"—there is already some commercialization of *Bacillus thuringenesis* and nuclear polyhedrosis virus for *Heliothis* control in USA and Australia, but the cost: benefit ratios are not yet very favorable"**. Today both *Bt* and NPV are being produced commercially, and have been reported to be effective for controlling *Heliothis/Helicoverpa* in different countries. In addition to NPV, studies have shown that some strains of *Pseudomonas, Beauveria* and *Metarrhizium* are also effective in controlling *Heliothis/Helicoverpa*. Natural plant products such as neem and custard apple seed extract have also been used for *Helicoverpa* control under low to moderate levels of infestation. However, they have not been found to be as effective as the synthetic insecticides, and have not been adopted widely by the farming community.

Because of the movement of *Helicoverpa* populations from one field/crop to another, it becomes difficult for natural enemies to exercise effective control over the populations of these pests. While *Heliothis / Helicoverpa* resort to long distance migration, the natural enemies probably are restricted to local movements. Biological control as a component of IPM also involves managed deployment of the natural enemies to control insect pests. Since there is a need to produce large numbers of parasitoids or predators economically, emphasis has mostly been restricted to *Trichogramma* and *Chrysoperla* species that are amenable to mass rearing. Despite moderate success in some areas, the results have not been very encouraging. The major constraints to large-scale adoption of biological control have been: i) problems with mass production, ii) lack of stress tolerance, iii) lack of versatile delivery system, and iv) incompatibility with insecticides.

Abundance of natural enemies should be an important consideration in determining ETLs. To date, there are very few quantitative determinations of the role of larval predators and predation of adult moths. Information on moth predation might enlighten us as to how to manage these pests before they lay the eggs. In addition, there are strong insect host – natural enemy interactions. Some of the grain legumes such as pigeonpea and chickpea are highly inhospitable to the natural enemies such as *Trichogramma* and probably to other small-bodied parasitoids because of the presence of glandular exudates. Therefore, there is a need to develop crop varieties that are hospitable to the natural enemies of the crop pests. This would have the same effect as the development of varieties with resistance to the target pest. There is an urgent need for future research on:

- Improving mass production and delivery system.
- Genetic engineering of bio-control agents.
- Improving formulations and quality control of bio-pesticides.
- Developing strains of natural enemies resistant to chemical pesticides and environmental stresses.
- Improving bio-efficacy and shelf-life of bio-pesticides and natural pant products.

Chemical control

Use of chemical pesticides is still the most prevalent practice to manage *Heliothis/Helicoverpa,* especially for high value crops such as cotton and vegetables. The *Heliothis / Helicoverpa* infestations are difficult to control even with insecticides as early instar larvae burrow into flowers, pods and bolls, and therefore it is difficult to direct insecticide sprays on to the larvae. As indicated earlier, the indiscriminate and excessive use of chemical pesticides has also resulted in development of insecticide resistance and resurgence of pest populations. This problem has been further complicated by the use of poor application equipment, unreliable products in the market and poor choice of insecticides. Therefore, cautious decisions have to be made on the dose and method of application based on ETLs. It is always preferable to alternate the pesticides with different modes of action so that insects do not develop resistance. The ETLs on some crops need to be much higher because of the compensatory ability of the crop, and the activity of natural enemies should be an important input when deciding on ETLs. There is a need to focus on directing sprays against insect stages (pupae, adults and eggs) preceding infestation. When insecticides are used against larval stages, it is important to ensure that the insects are caught early enough. There is a need to focus on pesticide application methodology to increase the efficiency of chemical control. Controlled droplet application is better than conventional high volume spraying, and therefore, there is a need to popularize this technology amongst the farmers worldwide.

During the 1981 workshop, it was stated that "**the fact that resistance of *Heliothis* to pesticides would create a problem in many areas has been alleviated temporarily by the production of new insecticides, including synthetic pyrethroids**". This expectation was short-lived, as *Heliothis/Helicoverpa* populations developed resistance to these insecticides at a much faster rate than to other chemical insecticides. This only points to the need for rational deployment and cautious application of synthetic insecticides for pest management. There is a need to adopt insecticide resistance management on an area wide basis. The insecticide resistance management strategies should include:

- Use of natural enemies, bio-pesticides or soft chemicals in the beginning of the season.
- Use seed-dressing or selective chemicals early in the season against secondary pests.
- Apply strong chemicals during peak infestation and rotate chemicals with different modes of action.
- *Reduce pesticide dosages in combination with botanicals and bio-*pesticides.
- Adopt resistance monitoring and resistance management strategies on an areawide basis.

Integrated pest management

Considering the complexity of effectively managing *Heliothis/Helicoverpa* infestations, it is imperative that we follow an integrated approach. This integration will involve agronomic and cultural management, host plant resistance, biological control and judicious use of chemical pesticides. A thorough analysis of multi-trophic interactions in the context of benefits versus crop damage and yield loss should form the basis of deciding the management options. At the same time, we should explore the possibilities of maximizing the efficacy of insecticides, while minimizing their harmful effects on the environment. Long-term climatic and insect population data should be used as an early warning system to advise farmers regarding the appropriate management practices to minimize damage by *Heliothis / Helicoverpa*.

Field monitoring and determining economic threshold levels for different crops and cropping systems is essential for a rational pest management effort, especially for application of chemical pesticides. Though ETLs based on eggs and small larvae have been estimated for different crops in different parts of the world, they are difficult to follow as they are based on precise sampling and monitoring on a daily basis. There is a need to develop ETLs based on crop phenology, the compensatory ability of the crop, varieties grown, abundance of natural enemies, cropping systems followed and the nature of intervention; whether to resort to insecticide applications, take up release of natural enemies, or application of bio-pesticides.

Cultural manipulation of crops such as time of sowing, cropping pattern, spacing and fertilizer application can be used to minimize *Heliothis / Helicoverpa* damage, but are difficult to follow by the farmers. Deep ploughing, interculture operations and flooding reduce the survival of pupae, and thus the population build up of these pests. Intercropping or strip cropping with marigold, sesame, coriander and sunflower can minimize damage to the main crop. Strip-cropping also increases the efficiency of chemical control. However, it is difficult to maintain the trap crops in active stage throughout the crop growing season, and at times, these simply lead to an increase in pest infestation on the main crop. While it is imperative that we follow the IPM approach, we must keep in mind that:

- IPM is quite complex – Needs regular communication between scientists, NGOs and farmers. Farmers will not wait for the IPM to act for the next season, but their immediate concern is to save the investment made on the crop.
- Farmers' misuse pesticides, but will they not do the same with other strategies? There is a need for foresight, education and communication.

Many potential elements of *Heliothis / Helicoverpa* management have been studied and recommended, but most are not sufficiently advanced to be of value to the farmers in practical management of *Heliothis / Helicoverpa* under field conditions. Public—private sector partnership in production, distribution; and quality control of different components of IPM such as resistant varieties, natural plant products, bio-pesticides and natural enemies is imperative, otherwise we will continue to talk of alternative methods of control for another 100 years.

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