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Management of *Helicoverpa armigera*: A Review and Prospectus for Pakistan

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Abstract: *Helicoverpa armigera* is a key pest of agriculture and horticulture in Pakistan. Costs of management and damage are gigantic in a wide range of food and fiber crops. It has been recorded on more than 100 cultivated and wild host plants. Key factors contributing to the pest status of *H. armigera* are its polyphagy, mobility, diapause and high fecundity. Control of *H. armigera* heavily depends on the use of chemical pesticides. However, resistance to all commercially available insecticides has been detected in *H. armigera*. The increasing emergence of resistance problems means there is an urgent need for the development of management strategies, which are less dependent on chemical insecticides and/or less conducive to the development of resistance to the control measures, used.

Key words: *Helicoverpa armigera*, biology, ecology, genetically engineered plants, biological control, *Bacillus thuringiensis*, *Baculoviruses*, Chemical control and integrated pest management

Introduction

The cotton American bollworm, *Helicoverpa armigera*, is the most devastating pest of agriculture in Pakistan, attacking a wide range of cash and subsistence crops. The pest is a problem in a variety of crops and climatic zones in Pakistan. *H. armigera* is usually the dominant pest on cotton, chickpea and other legumes, tomatoes and it also damages maize, sorghum and some vegetables (Common, 1953; Pearson, 1958; Reed and Kumble 1982; Topper, 1987). *Helicoverpa* and *Heliothis* are two genera of heliothine, noctuid moths that contain some of the most destructive agricultural pests worldwide. These include *Heliothis virescens* F., *Helicoverpa zea* Boddie, *Helicoverpa armigera* (Hubner) and *Helicoverpa punctigera* (Wall.). All four species were formerly included in the genus *Heliothis*; however taxonomic revision has led to the recognition of a new genus *Helicoverpa* (Hardwick, 1965).

Table 1: Consumption of pesticides in Pakistan

Year	Quantity (Tones)	Value (Million Rupees)
1990	14743	4581
1991	20213	5536
1992	23367	6554
1993	20279	5384
1994	24869	5808
1995	43373	7273
1996	43219	9987
1997	44872	9904
1998	41576	6960

Table 2: Production loss due to insect pests of cotton

Year	Loss in Production (000 Bales)
1992-1993	250
1992-1994	1650
1994-1995	2500
1995-1996	2000
1996-1997	2700
1997-1998	2800
1998-1999	3050

H. armigera costs the crop protection sector millions of rupees per year in management and lost production (Table 1, 2). This cost is rising as the insects become more resistant and as the area of susceptible crops increases. This review is limited to *Helicoverpa armigera* for its economic importance in Pakistani agriculture.

Consequently, the literature on its biology, ecology and management is vast. Research and status of use of host plant resistance, biological, chemical, biorational to control *H. armigera* have been summarized. Pathways for further exploiting the potential of IPM are emphasized.

Distribution and pest status: *Helicoverpa armigera* has one of the widest distributions of any agricultural pest, occurring throughout Pakistan, India, Central Asia (former USSR states), southeastern Asia (China, India, Pakistan, Thailand), Africa, Middle east, southern Europe (Spain, Portugal, Turkey and Greece), eastern and northern Australia, New Zealand and many eastern pacific Islands (Mohyuddin, 1989; Common, 1953; Commonwealth Institute of Entomology, 1967a,b, 1968, 1969; Hardwick, 1965; Zalucki *et al*., 1986). Economic losses, both from direct yield reduction and from the cost of chemicals, application and scouting required to control them, may be considerable (Table 1, 2). Annual estimates of damage include US $ 300 million only in Indian legumes by *H. armigera* (Reed and Pawar, 1982). The level of damage to other crops varies greatly throughout the world and among species, making generalization difficult.

Host plants: In Pakistan, *H. armigera* has been reported from 40 plants species belonging to 19 families (CIBC, 1969; Mohyuddin, 1989) which include crops, weeds and ornamentals. It has been recorded from more than 100 cultivated and wild host plants in Pakistan (Attique, 1999). There must be many other host plants in Pakistan but more studies are needed to record more host plants. Worldwide, *H. armigera* has been recorded from at least 60 cultivated and 67 wild host plants in India (Reed and Pawar, 1982). Lists of host plants are available for Africa (Pearson, 1958), Australia (Zalucki *et al*., 1986), New Zealand (Thanee, 1987).

Biology: *H. armigera* is fruit feeder, though leaves of crops such as potato and tobacco undergo most damage. Consequently, they are in direct competition with humans for food and fiber. Fruit parts fed by larvae are either rendered unusable or greatly reduced in quality and feeding often facilitates infection by pathogenic organisms. It is a multivoltine with diapause, highly fecund and capable of moving long distances as adults (Fitt, 1989). Thus, they can rapidly exploit host crops, particularly monocultures. Another important factor contributing to its pest status is the relatively

Table 3: *Bacillus thuringiensis* based genetically engineered commercial products worldwide

Product	Company	Trait	Brand name
Corn	Novartis	Resistance to corn borer (Bt toxin)	Maximizer™
Corn	Mycogen	Resistance to corn borer (Bt toxin)	NatureGuard™
Corn	Monsanto	Resistance to corn borer (Bt toxin)	YieldGaurd™
Cotton	Monsanto	Resistance to bollworms	Bollgard™
Potato	Monsanto	Resistance to Colorado potato beetle (Bt toxin)	NewLeaf™

Table 4: Registered Bt based biopesticides in Pakistan

Brand Name	Common name	Target pest	Company
Agree (50 WP)	*Bacillus thuringiensis*	Lepidoptera	Novartis, Pakistan
Condor (7.5 FS)	*Bacillus thuringiensis kurstaki*	Lepidoptera	Agrevo, Pakistan
MVP bioinsecticide	*Bacillus thuringiensis kurstaki*	Lepidoptera	National Pesticide, Pakistan
Larvo Bt	*Bacillus thuringiensis*	Lepidoptera	National Pesticide, Pakistan
Bactospine (1600 WP)	*Bacillus thuringiensis*	Lepidoptera	Pakistan Agrochemicals, Pakistan
Thuricide (1600 WP)	*Bacillus thuringiensis*	Lepidoptera	Agrevo, Pakistan

Table 5: Active ingredients in commercial products currently available for crop protection

Active Ingredient	Number of Products, worldwide	Number of Products in Pakistan
Bacteria	104	6
Nematodes	44	0
Fungi	12	1
Viruses	8	0
Protozoa	6	0
Insects	107	0

Table 6: Area, production and yield of cotton in Pakistan

Year	Area (000 ha)	Production (000 bales)	Yield (Kg lint/ha)
1990-91	2662	9628	615
1991-92	2824	12800	768
1992-93	2807	9289	563
1993-94	2805	8041	493
1994-95	2650	8697	562
1995-96	2997	10959	602
1996-97	3136	9300	476
1997-98	2959.7	9183.8	528

Table 7: Average yield of cotton lint in cotton growing countries

Country	Lint kg ha^{-1}			
	1992-93	1993-94	1994-95	1995-96
World	680	680	720	720
Egypt	1160	1280	960	1200
USA	880	760	880	680
China	840	960	1040	1160
Iran	840	840	920	840
Brazil	440	480	920	840
India	360	360	400	400
Pakistan	720	640	720	800
Sudan	480	520	640	600
Turkey	1040	1200	1240	1240
Mexico	880	840	880	680

large size and quick development. It completes development from egg to adult in less than 30 days; consequently, food is consumed at a high rate.

Life cycle

Moth: *H. armigera* fore-wings colored brown with small spots on the marginal sides, a bean shaped black spot on the ventral surface at the base is also visible. Hind-wings colored white and carry black dot at the rear margins. The female moths sized 18-19 mm in length with a wingspan of 40 mm.

Table 8: Area, production and yield of chickpea in Pakistan

Year	Area (000 ha)	Production (000 tones)	Yield (Kg/ha)
1990-91	1092	531	1401
1991-92	997	513	1419
1992-93	1008	347	1364
1993-94	1045	411	1380
1994-95	1065	559	1481
1995-96	1119	680	1457
1996-97	1100	594	1445
1997-98	1105	773	1440

Economic survey of Pakistan, 1998

Table 9: Resistance levels of insecticides in *Helicoverpa armigera*

Insecticide	Resistance Factor
Endosulfan	194
Profenofos	13
Chlorpyrifos	33
Thiodicarb	7
Cypermethrin	105
Alphacypermethrin	57
Zetacypermethrin	213
Deltamethrin	55
Lambdacyhalothrin	44
Bifenthrin	52
Cyfluthrin	55

Source: CCRI, Multan

At the vertex of the tail, hair tufts can be seen. Male moth sized smaller and owns a wingspan of 35 mm. Moths are habitually nocturnal and emerge from the pupae in the wee hours of morning. Moths prefer to mate in nighttime. Female moths lay their eggs from 2nd to 7th days of their life span. Life span of moths depends on the availability and quality of foodstuff.

Egg: Freshly laid eggs are usually pale white, eventually turn pale brown. Eggs turn dark brown before hatching. Eggs are ridged and clinodome shaped. A female moth lays 150-1500 eggs during its life span with an average of

450 eggs. Eggs usually laid between 9-12 midnight.

Larva: Larva passes six instars. Freshly hatched larva colors white and later turns pale. Head, thorax and legs turn brown and faint red markings appear on the dorsal surface. Second instar larva becomes pale white and black spots prominent on the body. First instar larvae measures 1.75 mm in size. Second and third instars, vary 3.5-4 mm and 9-10 mm respectively. As larvae pass through 4th, 5th and 6th instars, their body color changes according to food and weather conditions. A full-grown larva measures 35-42 mm in length. In later instars, stripes, continuous or broken appear on the dorsal and lateral sides. White hairs also can be seen as soon as larva approaches last instar. Freshly hatched larva gets its food from the broken egg and later on eats part of leaves on which egg was laid. Larva prefers squares or flowers in its cocktail. Young larva rarely attack bolls but bigger larva fondly feast on bolls. In the last instar of its development, larva consumes 80% of its food and spread havoc in the crops. Cannibalism is also present in the bigger larvae. Bigger larvae often travel on different parts of plant and attack other larvae and eat them. Bigger larvae bore into the fruitings and consume the inner contents by inserting their heads into the fruits, the lateral part of their body remained outside the fruit. The time span of larvae depends upon factors like temperature, humidity etc. Larval stage completed in 15-30 days depending upon the weather conditions. It leaves the feeding spot and crawls down on the ground for pupation. It burrows into the soil approximately 2.5-17.5 cm deep depending on the soil texture for pupation.

Pupa: Pupa is colored brown and measures 14-18 cm in length. It's anterior and posterior, both ends are round and two spikes can be seen on posterior side. The moth emerges in 5-8 days in summer and in case of any type of diapause, it may take several months.

Ecology

Polyphagy: *H. armigera* is highly polyphagous pest. Polyphagy play a vital role in pest population persistence and increase by a) populations may develop simultaneously on a number of hosts within a region, b) populations may develop continuously during suitable periods by exploiting a succession of different cultivated and uncultivated hosts through the season and c) population can persist at low density in seemingly unsuitable areas since females have a high probability of locating a host able to sustain larval development (Fitt, 1989).

Mobility: The ability to move long distances is the second major factor leading to the success of *H. armigera* as pest after polyphagy. *Helicoverpa* adopts two strategies to cope with the seasonality of their habitat; spatial redistribution by migration and diapause through periods of cold or drought (Farrow and Daly, 1987). However, local movements within crops and between nearby alternative crop and wild hosts are also important in the seasonal dynamics of these pests, especially in diverse cropping systems where feeding and oviposition sites may be continuously available.

Diapause: Another key factor in the life cycle of *H. armigera* is the ability to enter a diapause as pupae. Diapausing pupae are more tolerant of harsh weather conditions like cold and dry conditions (Eger *et al*., 1982; Roome, 1979). Photoperiods of 11.5-12.5 hrs, accompanied by low or decreasing mean temperatures of 19-23°C, are optimal for diapause induction (Hackett and Gatehouse, 1982; Hardwick, 1965; Pearson, 1958; Roome, 1979). Diapause defines the seasonal occurrence of *H. armigera* in many areas and contributes to their pest status by maintaining local population during periods when hosts are unavailable or conditions are not conducive to reproduction and population survival.

Fecundity: A key factor contributing to the pest status of *H. armigera* is high fecundity, which enhance with a short generation time, gives it an impetus for population outbreaks. Reed (1965) reported upto 3000 eggs from a single female. Fecundity in *H. armigera* is influenced by temperature, humidity and nutrition of adult and larvae (Nadgauda and Pitre, 1983). The highly variable estimates of fecundity obtained by different workers reflect differences in the way adults are maintained in the laboratory. There are no estimates of realized fecundity in the field and it is not clear how well laboratory estimates apply.

Control measures

Host Plant Resistance: The development of crop cultivars that are resistant to or tolerant of feeding damage has great potential in the regional management of *H. armigera* (Hearn and Fitt, 1992; Kennedy *et al.*, 1987). Many crops display characters that can be exploited by breeders to reduce attractiveness to ovipositing adults or suitability for larvae to feed (Kennedy *et al.*, 1987; Thomson and Lee, 1980; Williams *et al*., 1980). The value of host-plant resistance (HPR) depends on the type of resistance, the behavior of the pest and the diversity of the cropping system. To some extent the plant breeder has sought to redress the balance so as to exploit some of the natural defense mechanism which exist in nature (Maxwell and Jennings, 1980). These plant based defense mechanisms depend on the factors such as temporal avoidance, physical and chemical defense.

Genetically engineered plants: Biotechnology or recombinant DNA technology has immense potential to influence and benefit Pakistani plant protection industry in future. Modern techniques of biotechnology offer great potential of moving any cloned gene from any organism into any other organism and confer much greater precision and speed on achieving results than conventional techniques. Biotechnology research and development are moving at a very fast rate in industrialized countries. Modern biotech can add greater precision and speed to plant breeding. Genetically engineered or transgenic crops contain genes from unrelated sources, plant or bacteria. It provides artificial techniques to move across natural boundaries. Genetic engineering of crops can make a major contribution to the production of such inherently resistant/tolerant varieties, since it opens up a virtually limitless source of germplasm variability from which to select *H. armigera* control genes for introduction into elite crop varieties. Genetic engineered crops should complement conventional plant breeding. Genetic transformation of an increasing number of crops of worldwide importance become routine (Riazuddin, 1994; Finch, 1994). At present, the question of where to find genes encoding insect resistance, becomes very important. Two approaches so far have been used successfully, one to use entomocidal bacterium *Bacillus thuringiensis* as a source of resistance genes and the other is to identify and use the insect resistance genes present in plant source. Inhibitors of proteolytic enzymes, Protease inhibitors, Thiol protease inhibitors, α-Amylase inhibitors, Lectins, have been identified so far as potential resistance sources from Plant. The first gene isolated and transformed successfully to another plant resulting in enhanced insect resistance from cowpea, encoding a trypsin/trypsin inhibitor (Hilder *et al*., 1987). CpTI had been shown to be effective antimetabolite against a range of field and storage pests including *Helicoverpa* sp. The tomato inhibitor II gene, when expressed in tobacco has also been shown to confer insect resistance (Johnson *et al*., 1989). To date, genes encoding various thiol protease inhibitors have been expressed in several different plant species (Gatahouse and Hilder, 1994).

An exquisite and perhaps the most effective and efficient delivery system for Bt toxins, is the genetically engineered or transgenic plant. The major benefits of this system are economic, ecological and qualitative. In addition to the reduced input costs to the farmer, the transgenic plants shield season long protection independent of weather conditions, effective control of bollworms, pod-borers, fruit borers difficult to reach with sprays and control at all stages of insect development. Transgenics have already been reported in more than 70 crop plants including cotton, corn, soybean, rape seed, sugar beet, tomato, potato and chickpea but the new varieties are yet to be used commercially (James and Krattiger, 1996; Krattiger, 1997). So far, three transgenic *Bacillus thuringiensis* (Bt) crops have been approved for commercial use in US-Corn, Cotton and potato, with many more under development (Table 3). The first ever transgenic plants were made in 1987 (Barton *et al*., 1987; Fischhoff *et al*., 1987; Vaeck *et al*., 1987).

Fig. 1: Distribution map of *H. armigera* in Pakistani agroecosystem

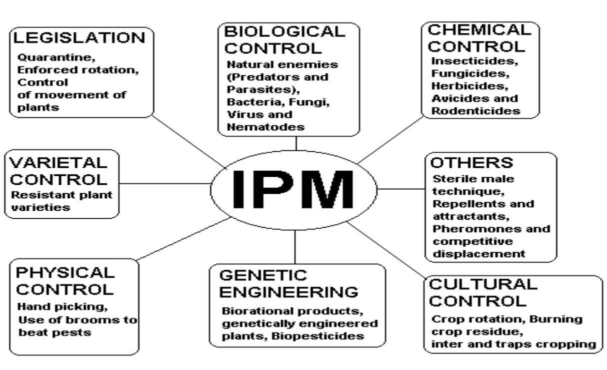

Fig. 2: Components of Integrated *H. armigera* management

"Bt Cotton" is cotton that has been maneuvered by means of biotechnology, with genes from environment friendly microbe, *Bacillus thuringiensis* to produce built in toxins for resistance to devastating insect pests of cotton. It is anticipated that Bt crops such as cotton, rice and chickpea will become available to Pakistani growers in next few years. Bt cotton is one of the first kinds of transgenic cotton that may become available to grower's in near future. It provides the cotton growing community an opportunity to harvest the benefits of plant biotechnology and to set a positive precedent for all future varieties of transgenic cotton or other biotech products. In order for genetic engineering to be not only environment friendly but also socio-economically reliable and attractive, more vigorous and focused research and development approach, especially by the public sector, is a must. The private sector should also be encouraged to achieve the desired goal of sustainable development through the use of genetic engineering. The potential of biotechnology is far from being fully exploited since applications are being held in check by the need for still more research to ensure that there are not harmful effects and by the slow pace of evolution of regulations governing the release of genetically modified organisms or products for general use. Recent trends in development and application of modern biotechnologies have given rise to certain socio-economic, environmental, legal and policy concerns. Genetic engineering is relatively a new technology and many countries closely regulate the testing and commercial release of transgenic organisms. In Asian countries, National Biosafety Committee develops policies to regulate the use of transgenic plants. The testing and field trials of Bt plants are important to evaluate not only the effectiveness of insect pest control but also strategies for the sustainable use of the plants and interactions of Bt cotton with management practices for other pests. In Pakistan, Government of Pakistan is currently developing Biosafety regulations to govern field trials and release of transgenic organisms such as Bt transgenic crops and microbes. In US and Europe, field trials of genetically engineered crops have been in progress since 1986. These include restricted access of developing countries to modern biotechnological products and techniques because of the tightening of intellectual property protection systems.

As in the case with all insecticides, insect pests will develop resistance to Bt toxins. It is not possible to predict how long Bt will remain effective but the development of pest resistance to Bt toxins can be slowed by careful design of Bt cotton plants and use of appropriate strategies for the deployment of these built in resistant plants in grower's fields.

Cooperation among scientists, governments, crop protection industry and growers is essential if the two most important potential benefits of Bt cotton are to be realized; sustainable control of cotton pests and reduced use of chemical insecticides. These goals can be achieved if Bt cotton is grown only in areas where it is needed and is not released to farmer's until researchers have developed satisfactory Bt local varieties, a plan for their sustainable use based on Pakistani conditions and a thorough program to enable growers to learn that Bt cotton should be avoided to treat with chemical pesticides for control of pests. More research on environmental impact of Bt cotton remains to be done in Pakistan.

Biological Control: Biological control occurs in nature when populations are limited through the action of parasites, predators and pathogens. As an applied science, biological control often involves releases of exotic natural enemies in an attempt to suppress introduced pest species but it is also implemented through the augmentation or conservation of natural enemies. Hundreds of successful biological control projects have subsequently been carried out around the world. Biological control stands today as a cornerstone of integrated pest management (IPM) and is the foremost alternative to the use of chemical pesticides (Greathead, 1986; Wratten, 1987; DeBach and Rosen, 1991). Successful projects demonstrate the circumstances under which natural enemies play an important role in the regulation of host populations; failures highlight questions concerning a range of ecological issues including the dynamics of predator-prey and parasitehost interactions, colonization events, competition and community structures (Huffaker *et al*., 1976; Hussel, 1986; Luck *et al*., 1988). Indeed attempts to explain and remedy failures of biological control often serve as the impetus for considerable research on the ecology and basic biology of the systems involved (Mohyuddin, 1981).

Naturally occurring predators and parasites are important in regulating *Heliothis* populations (King and Jackson, 1989). In the absence of chemical insecticides, natural enemies have the potential to maintain *Heliothis* populations at the sub-economic levels. Conservation, augmentation and release are the three main steps in biological control of *Helicoverpa*. Conservation is the basic of any biological control program, it gives us the understanding of what natural enemies are doing in a crop and to seek effective and economical ways to protect or enhance the pest control. While conservation is perhaps the most cost effective and universal form of biological control, it is also highly local and has flourished most where researchers have had a keen interest in protecting particular areas of crops, as in the plantation industry (Sterling *et al*., 1989).

Augmentation involves the mass production of natural enemies usually local species and their release on crops. Traditionally, this has been aimed at control of particular pest populations, i.e. the natural enemies have been applied like chemical insecticides. Mass production and use of egg parasitoids of moth pests, *Trichgramma* sp. Commercialization in developing countries is limited but growing. Prospects for development of augmentation in Pakistan are good: Technologies are not complex, labor is available and incentive to internalize Helicoverpa control economics is great given the foreign exchange currently expended to import chemical pesticides.

A propagation and release program should proceed in a logical manner, beginning with colonization of *Helicoverpa* sp. and a natural enemy ending with utilization of the natural enemy and economical suppression of *Helicoverpa*. First the natural enemy must be collected and colonized on cultures. Ability to propagate the natural enemy is a prerequisite to studies on host-or-prey –natural enemy interactions and field evaluations. Finally, economic feasibility must be assessed before the technology can be recommended and implemented.

Microbial Control: There is some prospect of bio-rational insecticides becoming available for use against *H. armigera*, e.g. *Bacillus thuringiensis* (Bt), spray or transgenic crops, nuclear polyhedrosis viruses (NPV). However, resistance to bio-rationales is likely to evolve rapidly unless they are used as part of a coherent resistance management strategy.

Bacteria: One key group of products for crop protection without chemicals is bacterial biopesticides preparations or formulations manufactured to be applied in the control or eradication of pests in which the active ingredients or principle is based on a living organisms. At present, the use of biopesticides in Pakistan is negligible and worldwide still present well below 1% of crop protection. The major product group is based on *Bacillus thuringiensis* (Bt), a gram positive and spore forming bacterium, which is the most widely used microbial agent to control insect pests of agriculture, forestry and even public health. Various Bt strains produce different pesticidal protein toxins which are used as insecticides and have specific host range (Karim and Riazuddin, 1997). Bt is known for its pesticidal proteins that kill the insects. These proteins are quite selective in their toxicity to specific insect pests. Ingestion of δ-endotoxin protein is a must for susceptible larvae, the crystal protein is solubilized in the alkaline midgut and then activated by digestive enzymes to yield a proteolytically stable toxin. The activated toxin passes peritrophic membrane and binds to specific receptors in the brush border membrane vesicles. It opens up the K^+ channel in the membrane and eventual cell lysis causs death of the insect (Karim and Riazuddin, 1997). These naturally occurring insecticidal proteins have been commercially produced and used as insecticides for decades. An extensive body of safety to human and animals and the absence of adverse effects on non-target organisms and the environment. The present worldwide use of biopesticides is estimated to be less than 1%. Over half Bt based biopesticides are being consumed in the USA, with a total worldwide market of biopesticides of US $ 24 million in 1980. This market grew to US $ 107 million in 1989; at current annual growth rates of 11%, it will exceed $ 300 million by the year 2000 (Feitelson *et al*., 1992). A recent steep increase in sales of Bt products has occurred due to improvements in formulation and production which have provided most cost-effective products, some of which can compete directly with chemicals. Biopesticides have been the major focus in the crop protection industries of developing countries, where their use is limited to see the efficacy in local conditions. Though, the use of Bt based products in most developing countries overall depends on imported commercial preparations, Several countries including Pakistan now have invested their public resources for the development and production of Bt based products by their own to develop cheap technology (Karim *et al*., 1999). China is a pioneer in this region and Wuhan province is the hub for Bt biopesticide production. Bt products have been extensively used in 30 provinces to control food and crops insect pests including *H. armigera*. An estimated 8 million hectares of farmland is being protected with Bt in China (Xie *et al*., 1990). In former # USSR, the routine use of Bt to protect crops is a well established story (Rimmington, 1989). In Pakistan, so far six Bt based products (Table 4 and 5) had received the approval of Plant Protection department, Government of Pakistan (Karim and Riazuddin, 1999). None is yet at significant volumes of sales in Pakistan but prospects are now better than ever before. Bt does have a valuable role to play within integrated pest management program currently being developed for major food and fiber crops. The efficacy of Bt on *H. armigera* is known and an exploration of new approaches to armored control currently underway may soon result in an expanded role for Bt to control this pest. The persistence of Bt efficacy must be greatly improved to achieve the necessary degree of control. Such improvements require the use of isolates with greater toxicity towards *H. armigera*, optimized application methods and a better understanding of the mechanisms responsible for the degradation of Bt on foliage so that direction can be provided for research into improved formulation.

Fungi: The role of entomopathogenic fungi in causing disease in insects is a well recognized . Despite the early enthusiasm for the technology to control insects, the prelusion of cheap but effective chemical insecticides reduced interest in the use of pathogenic fungi. The rapid developments in the field of molecular biology, there has been a resurgence of exploration of their potential, prompted by the realization that chemical insecticides pose problems for the environment and are expensive to use. In Pakistan, only one *Beaveria bassiana* based product has shown its presence in the registration data base of Plant protection department (Table 5) with out any imperative impact in local agricultural setup (Karim and Riazuddin, 1999). Entomopathogenic fungi are unlikely to capture any major part of the pesticide or biopesticide market but they do have a future in specialized applications and integrated approaches to control insect pests. *B. bassiana*, *B. brongniartii* and *Metarhizium anisopliae* are the well known cases of entomopathogenic fungi. There is a considerable potential to exploit these agents to control *H. armigera* in integrated approaches. The effectiveness of fungal control agents is determined by environmental conditions such as temperature, relative humidity, UV light and slow action to kill insects (Zimmermann, 1982, 1986; Walstad *et al*., 1970). In the long term, the use of genetic engineering offers the opportunity to improve entomopathogenic fungal biopesticides for the sustainable control of insect pests.

Virus: A wide variety of viruses have been identified for their characteristic to kill insect hosts. Many viruses have been identified in insect hosts such as baculoviruses (large, covalently closed, circular DNA genomes), poxiviruses (large, covalently closed DNA genome); cytoplasmic polyhedrosis viruses (segmented, double stranded RNA genome); picornaviruses (small, single-stranded RNA genome). Baculoviruses are infectious only to insect hosts and this makes them useful as insect biocontrol agents. Baculoviruses have been isolated from over 600 species of insects including Lepidopteran, Hymenopteran and Dipteran orders (Possee and King, 1994). There have been numerous examples of the use of baculoviruses worldwide to control insect pests. Baculoviruses have been used in experimental field trials to control *Helicoverpa* species in the USA. Their application has been limited because of the competition from other effective and quick biorationals. In China, larger areas of cotton crops have been sprayed with NPV (Guangyu, 1989). In Pakistan, no laboratory or field studies have been cited so far. One of the major disadvantages of using baculoviruses as pesticides in an agricultural settings is that it typically taken 4 days to 2 weeks to kill their insect hosts. During this period, significant crop damage occurs. Clearly, a pesticide which causes more crop damage in the short term, even if it successfully controls the population in the long term, is neither desirable nor marketable to a grower. Scientists have been trying to insert genes encoding insect specific hormones, enzymes or toxins into the virus genome to improve it for consumers (Miller, 1995). Baculoviruses have the great potential to be used in Pakistan to control *H. armigera* in integrated pest management. A thorough study is a prerequisite to exploit this agent in local conditions.

Nematodes: The free living, non-feeding infective juveniles of steinernematidae and Heterorhabditidae families of nematodes possess attributes of both insect parasitoids or predators. They have chemoreceptors and are motile and like pathogens they are highly virulent, killing their hosts quickly and can be cultured easily *in vitro*, have a high reproductive potential. They have a broad host range (Gaugler, 1981, 1988), are safe to vertebrate, plants and other non-target organisms (Akhurst, 1990). Entomopathogenic nematodes and their bacterial partners kill insects so quickly that they do not form the intimate, highly adapted host parasite relationships characteristic of other insect nematode infections. This rapid mortality permits the nematodes to exploit a range of hosts that spans nearly all insect orders (Pionar, 1979), a spectrum of activity well beyond that of any other microbial control agent. Insects are highly susceptible to infection in petri plates but are seldom impacted in the field, where nematodes tend to be quickly inactivated by the environmental stresses like dessication, radiation, temperature etc. (Kaya and Gaugler, 1993). Nematodes appear to be opportunists rather than biocides in the case of *H. armigera* (Glazer and Navon, 1990). Despite progress in their commercial development, entomopathogenic nematodes are not meeting their fundamental mission to any significant degree even in integrated approaches. Despite the larger number of efforts in nematodes research, the pipeline has not delivered nematodes or other biologicals as consistently effective ready to use technologies (Table 5). Genetic manipulation has been suggested as an approach for entomopathogenic nematodes to overcome limitations related to inadequate efficacy, stability and economics to realize their full biological control potential (Gaugler, 1987, 1993). Genetic improvement is based upon selective breeding, mutation and genetic engineering. In short, genetically engineered nematodes may play a significant role in the integrated pest management strategies of the future but emphasis should be given to exploit local treasure of nematodes.

Chemical Pesticides: Control of *H. armigera* almost everywhere relies heavily on the use of chemical pesticides. In Pakistan, yields of cotton were increased significantly by the introduction of insecticides (Table 6) but the release of a high yielding variety led to a dramatic fall in production due to the viral disease in recent years (Table 2). Increased and earlier indiscriminate use of organophosphates to control virus vector whitefly had a detrimental effect on the natural enemies of *H. armigera*, so this pest once a minor in status has also increased in importance. The number of spray applications has increased and local distributors are selling variety of generic products (Table 1). Some of these products are too toxic to be applied through manually operated sprays.

In chemical control of *H. armigera*, in recent years, authorities has started utilizing electronic media to advice farmers, who in the past without any adequate training, have misused chemicals while attempting to maximize their income in the short term. The big plunge in the production of cotton in Pakistan as compared to other cotton growing countries (Table 7) has encouraged efforts to introduce integrated pest management but adoption in many of these areas has been difficult and slow due to the scale of the problem and lack of cooperation between organizations and personnel.

Other Methods: Cultural Control: Many agronomic practices have been suggested for the management of *H. armigera* in various cropping systems, including manipulation of crop planting dates, stubble cultivation and destruction of crop residues, the use of closed seasons and destruction or manipulation of alternate hosts (Fitt, 1989). These measures achieve some degree of pest control either by destroying overwintering populations in soil or residues or by providing a host-free period during which populations are greatly reduced.

Area-Wide Suppression: In local conditions, control measures are usually applied on a farm to farm or crop to crop or field to field basis when infestation exceed economic thresholds. An alternative to uncoordinated control strategy is to develop community coordinated area wide systems to suppress pest populations to low levels. Area wide programs based on community coordinated synchronous application of pesticides to large areas in western countries covering many farms have been adopted successfully (Cochran *et al*., 1985). The appropriateness of this strategy depends largely on the movement behavior of the pest (Bellows, 1987). Management of *H. armigera* based on area-wide reduction using a range of available techniques; mass release of parasites or predators, application of pathogens, autocidal techniques and destruction of spring hosts. Nevertheless, the concept of area-wide suppression of *Helicoverpa*, where and when the population is small and localized at some time in the year, deserves careful consideration and much further research (Knipling and Stadelbacher, 1983).

Trap Cropping: In some cropping systems different crops act unintentionally as trap crops for *Helicoverpa* at particular times of the season. The manipulation of trap crops as diversionary hosts or to provide refuges for beneficial organisms that will later colonize susceptible crops has often been suggested (Pearson, 1958; Johnson *et al*., 1986) but rarely been applied in Pakistan successfully.

Insect Growth Regulators: The insect growth regulators (IGRs) were at one time considered to be the third generation of insecticides for great potential for curtailing agrochemicals use. The first ever IGRs, natural insect juvenile hormones, have outstanding efficacy under restricted conditions and examples such as the closely related methoprene and the more distantly related fenoxycarb and pyriproxyfen find use in limited trials and fields (Karim, 1999). Ecdysone agonist tebufenozide and analogs, a new development with adequate potency and outstanding selectivity, which provide a new and effective approach to the use of developmental inhibitors for pest control. An important discovery was that benzoyl phenylureas, exemplified by diflubenzuron, inhibit chitin deposition. Despite outstanding potency and apparent safety, these compounds are still limited in agricultural applications by slow action and a narrow range of sensitive stages in the life cycle. Other IGRs include the plant systemic Cryomazine, which inhibits larval development by an unknown mechanism and azadiractin, the major limoid in neem, which has antifeedant and antimoulting properties.

Pheromones: Studies of the use of pheromones against *H. armigera* indicate a possible use in monitoring populations but hold no immediate promise of a practical control measures. Pheromones play a vital role in manipulating insect behavior at extremely low levels without toxic chemical residues; they are important components of pest control programs that usually also require a chemical insecticide (Casida and Quistad, 1998).

Integrated pest management: It is clear that *H*. *armigera* poses a serious threat to agricultural production in Pakistan and it is unlikely that the problems will diminish without a thorough examination of the socio-economic, agronomic and pest control practices which have been responsible for elevating the status of the pest from minor to major with 20 years. The implementation by farmers of sound IPM practices against *H*. *armigera* represents a major challenge to Pakistani agriculture, which if ignored will result in serious consequences for the economic production of cotton (Table 6) and legume crops (Table 8).

Integrated pest management (IPM) refers to using the best possible combination of biological, physical and chemical methods to achieve effective and sustainable control of pests (Fig. 1, 2). In most crops, including cotton, use of an IPM program leads to a reduction of pesticide applications. Through the efforts of FAO, the adoption of IPM concept is spreading rapidly among growers. One local private company IPM consultants (Islamabad) is also promoting the idea of IPM in Pakistani cotton belt to minimize the use of chemical insecticides. Bt cotton is a new management tactic for cotton pests and it is important to consider how it will interact with existing IPM practices in cotton. Over the past several years, the primary importance of "natural enemies" in controlling cotton insect pests has been increasingly recognized. Another local company Vitova Insectaries, Multan is promoting the idea of biological control in private sector. The widespread introduction of chemical pesticides to cotton farmers devastated natural pests, particularly *Helicoverpa armigera*, once a minor pest, now got the status as the major pest. In contrast to chemical insecticides, the Bt toxins that will be used in cotton are not toxic to natural enemies. One of the most notable potential benefits of Bt cotton is that it leads to a decrease in insecticide use by growers, who often attempt to control cotton pests with insecticides. If growers are provided with demonstration of resistance of Bt cotton to its insect pests, perhaps by participating in ongoing farm research to learn for themselves, many may decide to eliminate or minimize sprays directed against these pests. Demonstration programs and information campaigns involving farmers, extension workers and researchers will be necessary to achieve this goal.

Pesticide resistance: *H. armigera* has troublesome ability to develop resistance to all kinds of insecticides. Resistance to DDT, Organophosphates insecticides and synthetic pyrethroids has confused attempts at chemical pest control and in some cases, has forced abandonment of cropping due to the inability to control it. *H. armigera* provides an abundance of resistance mechanism to explore and a challenge to apply this basic knowledge to design effective and practical strategies for resistance management and prevention. *H. armigera* has developed high level resistance to DDT, organophosphates, Pyrethroids, endosulphan, carbamates and is also likely to become resistant to Bt. Resistance is a widespread menace in Pakistan (Table 9), China, India, Australia, Thailand and has been documented from many countries (Gunning *et al*., 1984; Ahmad and McCaffery, 1988; Armes *et al*., 1996; Jadhav and Armes, 1996; McCaffery *et al*., 1989, 1991; Daly and Murray, 1988; Ahmad *et al*., 1995, 1997). It is widely believed that organophosphate and carbamate resistance is due to decreased penetration, increased detoxification and/or insensitive Ache (Gunning *et al*., 1994, 1996b; Chitra and Reddy, 1993). Pyrethroid resistance is caused by decreased penetration, increased hydrolysis, increased metabolism by monooxygenase and or nerve insensitivity (Ahmad *et al*., 1989; Ahmad and McCaffery, 1991; Gunning *et al*., 1995, 1996a; Phokela and Mehrotra, 1989).

Studies showed that variation in levels of insecticide resistance arise from interaction between local selection pressure and the movements of resistant and susceptible moths from different populations within Pakistan. Below are highlighted some of the reasons why the pest status of *H. armigera* has increased in Pakistan in recent years, with emphasis on the ecological migration in the development, maintenance and spread of insecticide resistance.

As *H. armigera* spends a substantial amount of its time within agroecosystems, it is subject to intense selection for genotypes resistant to a variety of insecticides. This is particularly the case for populations of cotton, where insecticides are often applied at intervals throughout the growing season (6-8). Cotton receives most of pesticides now used in Pakistan. Field control has been maintained in Australia in spite of high levels of resistance, by targeting eggs and small larvae and by restricting the use of different groups of insecticides to defined periods in the growing season. But even here there are recent evidences that resistance management is breaking down. The cropping situation in Australia is essentially simpler than in Pakistan, a relatively small number of individuals farm large areas of land as monocrops (thus it is much easier to apply insecticide efficiently), planting times are synchronized as farming operations are dictated by irrigation timings by winter season when no crops are grown and the agricultural extension service is well established. This contrast with Pakistan where large number of independent small farmers grow a wide variety of crops and it would be difficult to implement a resistance management strategy similar to the Australian one. Even if some of the farmers were persuaded to adopt strategy, their crops would still be subject to the immigration of resistant moths from neighboring non-cooperating farmers. Thus, there is an urgent need for the adoption of integrated pest management and resistance management strategies in Pakistan, so that the amount of insecticide applied against *H. armigera* can be reduced.

Though, much useful general information can be gained by studying insecticide resistance mechanism in model systems such as *Drosophila melanogaster* Meig. (Wilson, 1988), the specific information required to understand and manage insecticide resistance in crop pests must be based on genetical studies of the *H. armigera* itself. This rationale should motivate our current research programs in Pakistan, research should focus on linkage mapping of resistance mechanisms. In *H. armigera*, delaying and managing resistance to Bt toxins expressed crops could be greatly hindered by our incomplete knowledge of the mode of action and resistance mechanisms.

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