REVIEW OF LITERATURE
REVIEW OF LITERATURE

The literature pertinent to the subject of the thesis has been reviewed under the following heads:

I. Host Plant Resistance

II. Impact of abiotic factors on seasonal incidence

III. Use of pheromone traps

IV. Life table studies

V. Management Strategies

Host Plant Resistance

In India, *Helicoverpa armigera* is the predominant species causing economic damage to most of the crops. Goyal and Rathor (1988) tested the susceptibility of different host plants to *H. armigera* and found it in the order gram > pea > linseed > arhar > tomato > cotton. They also reported that *rabi* host is more susceptible than *kharif* one. Chick pea was found as the most suitable host on the basis of growth index (GI) followed by soybean (Bilapate *et al.*, 1991).

Many workers had made attempts from time to time to test the susceptibility of *Cicer arietinum* varieties against *Helicoverpa armigera* so as to screen out resistant chickpea genotypes. For example: GL-645, P-1324-II, P-1697, P-6292-I, DULIA-6-28, GGP and Selection-418 (Chhabra and Kooner, 1980), H-75-85 and ICCC-18 (Dias *et al.*, 1983) RSG-130 (Patnaik *et al.*, 1985), L-2793 (C-235) (Ujagir and Khare, 1987), variety 1115 (Iqbal *et al.*, 1992), ICC-506 (Bhagwat *et al.*, 1995), BG-256 (Patnaik and Mohapatra, 1995), PDG 90-3E (Yelshetty *et al.*, 1996) Kouroush (Gumber *et al.*, 2000), RG-945 and JAK-19224 (Banchhor *et al.*, 2000), Chaffa and ICCV-10 (Bhatt and Patel, 2001), C-44 and Paidar-91 (Shakeel, 2001), ICC 9854 and ICC 12490 (Sanap and Jamadagni, 2005), BGD-74 (Chandraker *et al.*, 2006) were found to depict tolerant response against the pod borer damage.

The difference in the infestation at different growth stages of chickpea plant could be accounted due to the relative amounts of the bio-chemicals present at a particular stage (Kaushik and Naresh, 1984). The crop phenology is also related with
the pod-borer incidence at the vegetative, pod formation and flowering phases (Joginder et al., 1985). Among the desi and bold type, the desi type chickpea against H. armigera was found to be less susceptible than the bold type (Das and Kataria, 1999). The variety GL-769 exhibited resistance due to low number of pods attacked (19.5), less seed weight loss (18.1 ) and damage (17.7%) and this condition was attributed due to asynchronization of peak activity of pod borer and most susceptible stage of the plant. While studying the relationship between the length of maturation period in gram and build up of the population of H. armigera, Lateef et al. (1985) advocated that efficient screening could be accomplished by comparing the genotypes which flower simultaneously. The late flowering genotypes tend to have lower percentage of pod-infestation. On plotting the percentages of pod-infestation against time to flowering, the more resistant genotypes can be distinguished as being those that are farthest from the regression line. These findings were contradicted by Ram and Khare (1987) who stated that late maturing genotypes suffered the greatest infestation and those with light colored foliage seemed to be preferred more by the pest. Further, the pod borer damage was positively correlated to the total number of pods (r=0.36), whereas the pod length and pod width had no such significance (Maurya and Ujagir, 2004).

Per cent pod damage could be converted to PSR (pest susceptibility rating) on a scale of 1-9 as suggested by Lateef and Reed (1983). Three different parameters viz. relative pest pressure index, relative intensity of damage index and relative productivity index were employed by Singh and Yadava (1999b) who found DHG-84-11, 9-240, BG-79 and DHG-88-20 to be more pest tolerant.

Patnaik and Senapati (2002) studied the spatial distribution of Helicoverpa armigera eggs in chickpea cultivars Annigeri 1, K-850, and H 208, sown at 15-day intervals from 30 October to 15 December. Statistical analysis showed that the spatial distribution of H. armigera eggs on chickpea was not influenced by sowing dates and cultivars. Oviposition was observed on different positions of the canopy and in the vegetative stage, the second terminal leaf had the highest proportion (25.7%) of eggs. The different indices of aggregation indicated the contagious type of egg distribution on chickpea.

Some of the wild varieties of crops can be used to develop resistant cultivars with diverse mechanisms of resistance, mapping population to identify QTL's
associated resistance and as a source of genes for cloning and genetic transformation of crops for conferring resistance to *Helicoverpa*. On a similar front, few accessions of wild relative of chickpea e.g. *Cicer biginum*, *C. judaicum*, *C. pinnatifidum*, *C. microphyllum* (Sharma et al. (2006) and *C. cuneatum* have shown diverse mechanisms of resistance to *H. armigera*.

**Use of pheromone traps**

The physical and biological environment has direct impact on the occurrence, build up, infestation levels, survival, rate of multiplication, life duration and epidemiology of the pest. The objective of successful pest management program lies in pest forecasting, monitoring their emergence and occurrence over space and time, geographical distributions, topography and phenological stages of the plants in any cropping system. In the array of various potential tools for pest control, Semiochemicals are being used as modern tools to monitor pest populations. The pheromone traps proved reliable for early detection and estimation of *H. armigera* population and establishment of ETL (Szocs et al., 1995). The efficiency of traps depends on the reliance rate of pheromone components in the specific rates from the septa. The compounds used were Z-11-hexadecanal (95%), Z-9-hexadecenal and hexadecenol (99%). Similarity dissipation patterns of the two aldehydes viz., Z-11-hexadecanal and Z-9-hexadecenal is due to the same molecular weight and similar chemical nature but due to a different functional moiety and different physical properties, the alcohol compound (hexadecenol) showed a different pattern, such dissipation follows the first order kinetics.

Monitoring techniques for measurement of population growth are in place and direct count of immature stages and mass-collection of adults in pheromone traps are important tools.

The pheromone trap catches were found to be negatively but significantly correlated with the wind speed (-0.393) and minimum temperature (-0.468). Temperature affected both the flight activity of male and release rate of pheromone from the septa and thus was negatively correlated with adult activity (Verma and Sankhyan, 1993).
A positive correlation for pheromone trap catches of *H. armigera* with larval population and damage to the fruiting bodies in the field of chickpea was reported by Prabhakar *et al.* (1998) and Trivedi *et al.* (2005).

Monitoring of *H. armigera* in pigeonpea and chickpea crop using pheromone traps revealed that the activity of *H. armigera* was maximum (98-134 moths/3 traps/week) during the last week of December 1996 to the third week of January 1997 in chickpea whereas in pigeonpea, the moth catches ranged between 2-22 moths/3 traps/week (Nakat and Ghorpade, 1999). The highest activity of the pest was observed during 39th and 40th meteorological week followed by the 2nd peak during 43rd and 44th meteorological week. The pheromone trap catches were positively correlated with rainfall ($r=+0.630$) in pigeonpea and to that of minimum humidity ($r=+0.723$) in chickpea.

Kant *et al.* (2004) assessed *Helicoverpa* population on the basis of sex pheromone released by females. Variable climate stimulate pheromone polymorphism, so *H. armigera* which is polyphagous and has habitats in varied climatic regimes, there is a possibility of existence of both host and environment type and possession of sex pheromone response polymorphism in males of *Helicoverpa* (associated with geographical locations). Therefore, for monitoring and mass-trapping, a bouquet of blends of the major components (Z-9-hexadecenal and Z-11-hexadecenal) be used rather than only one blend, provided the blends and their numbers will depend on the pre-determined location-specific pheromone profile of *H. armigera*. Varying blends were impregnated and the ratio of Z-9-hexadecenal to Z-11-hexadecenal varied from 0:100 to 15:85, further suggesting male sex pheromone response polymorphism (Tamhankar *et al.*, 2003).

Twenty days after installation of pheromone traps in field, replacing the old septa with freshly loaded septa, trapping efficacy is regained (Bhullar *et al.*, 2005). This further helps to develop a pesticide protocol and employment of pesticides judiciously at an appropriate time. The relationship between pheromone trap catches of *H. armigera* moths in egg, larvae, and damage to the cotton plant reproductive bodies were studied through the regression equations which were further employed for the prediction of egg and larval populations and eventual damage to the crop. Kant and Kannaujia (2006) described the morphology of sex pheromone gland of *H. armigera*. The pheromones of *Helicoverpa* have 5 components but the major ones (Z-
11 HDAL: Z-9 HDAL) are most effective in the ratio of 97:3. Modified ICRISAT standard pheromone traps contain rubber eraser septum, at a distance of 15m from each other and at a height of 1.5m above the ground level. Each day after installation, trapped moths were collected, counted and destroyed. The moths started appearing in traps during end of February, increase suddenly in the beginning of March (45-75 moth catches/day) and reached a maximum of 109 moths on 28th March. The number of moths started declining after 13th April (15-29 moth catches/day). The maximum population appeared from 1st March to 12th April. The trapping efficiency of septa decreased with time after field installation. The blend contains Z-9-hexadecenal and Z-11-hexadecenal in a ratio of 97:3 (Dixit et al., 2007).

Varshney and Sudha (2006) studied the shelf life of the septa impregnated with the pheromone component (hexadecenol) and 97.3 blend of Z-11-hexadecenal and Z-9-hexadecenal by Gas Chromatographic estimation for different time intervals, varying temperature and storage conditions. No losses was observed up to 8 weeks when stored in freezer (-10°C) or in fridge (5 °C), but a loss of 22% was found when stored at room temperature, so it was suggested that pheromone blend impregnated glass vials are better stored in fridge than to the rubber septum.

Hossain (2008) reported that the pod-borer moth catching in pheromone traps started between 3rd week of January to 2nd week of February and reached its peak in April and diminished to zero in the last week of July in the Pulses Research Centre, Pubna, Bangladesh and recommended the installation of IPM package from mid-January for its effective control.

**Impact of abiotic and biotic factors on seasonal incidence**

The population of insects is primarily controlled by weather which affects its development and survival. A high humidity ranging from 60-75% and temperature from 10-15°C accompanied with 3-5 mm rains during January could be a critical factor for the multiplication of *Helicoverpa armigera* (Patel, 1979).

Vaishampayan and Veda (1980) also suggested that minimum daily temperature of 10-14°C and RH between 50-70% is conducive for larval population. The relative humidity and pest incidence are closely related, the early and good rains (250mm) in September and October favored the buildup of the first generation of larval peak of pod borer, whereas winter rains favoured the population build up in
December, January and February (at least 25mm/month). According to Metho et al. (1985) uniform average low temperature (15±3°C) and RH (75±10°C) during January and February, respectively, is ideal for continued build up of pest population.

Tripathi and Sharma (1985) reported that a temperature range of 12-21°C and RH below 70% with low rainfall was responsible for high population of *H. armigera* in the terai belt of Uttar Pradesh. Heavy rainfall tended to wash the noctuid eggs of the plant and break down the pupation chambers in the soil preventing the adult emergence. Incidence commenced during the first week of January, population gradually build up and reached to its peak in February and March and suddenly declined at the maturity of the pods by the end of March. Maximum increase was reported in the ninth week with 18.42 larvae/6mt in 100% pod formation stage. The population decreased with increase in temperature from 29.5°C to 33.4°C. Positive correlation between maximum temperature and pest incidence was observed, correlation coefficient being 0.77 and 0.86, up to 100% pod formation. Minimum temperature also showed positive correlation.

Further, a sudden rise in the minimum temperature (>5°C) around 7-8 standard weeks and rainfall during 1-9 standard weeks along with a considerable adult moth catches (above 15/week) during 5-7 standard week triggered a major rise in the pest population during the 10-14 standard weeks (Souvenir, 2005).

Dubey et al. (1993) found that the pest had its peak activity in the months of February and March whereas Thakur et al. (1995) noted that the peak larval activity was from November to April under Jammu conditions. Maximum and minimum temperature as well as vapour pressure showed decreasing trends in contributing population fluctuation of *H. armigera* on chickpea. The pest was first observed in the third week of November and reached a peak in the third week of December when the crop was in the podding stage. The pod borer was active from November to February on chickpea (Patel and Koshiya, 1999). Alam (1996) and Khurana (1997) noticed the attack of *H.armigera* during the first week of March and recorded the maximum larval population at the end of fourth week of April, contradicting Shakeel (2001), who reported the attack of *H.armigera* on chickpea in the third week of March with the maximum population in the first week of April.
Singh and Ali (2006) studied the seasonal activity of the gram pod borer, *Helicoverpa armigera*, and its parasitoid, *Campoletis chlorideae*, on chickpea cv. K-850, using pheromone traps. The larval activity of *H. armigera* continued throughout the crop season with two peaks in both years, i.e. the first from 45 to 49 standard weeks and the second from 5 to 13 standard weeks. The highest mean larval populations of 6.3 and 6.4 larvae/m² were observed in 45 and 12 standard weeks, respectively. Minimum and maximum temperatures showed a positive correlation with both larval and adult populations of *H. armigera*, while relative humidity showed a negative correlation. Maximum parasitization by *C. chlorideae* was observed in 4 standard weeks. Parasitization declined from 44⁰ to 50⁰ standard weeks. Minimum and maximum temperatures showed a negative correlation and relative humidity a positive correlation with parasitization.

**Life Table Studies**

Life-table is a table of statistics of probability of life. It provides essential information regarding the schedule of mortality for a known cohort of individuals. They are one of the most useful tools in the study of insect population dynamics. These tables record a series of sequential measurements that reveal population change throughout the life cycle of a species in its natural environment. When these measurements are related to the several causes of mortality, the life-table forms a budget of successive processes that operate in a given population (Harcourt, 1969).

Pearl and Parker (1921) were the pioneers to study life-tables for insect populations of *Drosophila melanogasra* and *Tribolium confusum*, they were followed by life insurance agencies (Dublin and Lotka, 1925). The life expectancy of small animals (Leslie and Ranson, 1940), birds (Park, 1948) and laboratory culture of insects (Birch, 1948, 1953 a, b; Howe, 1953) were also dealt with later. Leopold (1933) studied natural populations. The classical publication of Pearl and Miner (1935) for lower organisms and “Life-tables for natural population of animals” by Deevy (1947) are some of the initial works. Later, Ito (1959), Slobodkin (1962), Morris (1963), Witter et al. (1972) Southwood (1978) dealt with life-tables and the importance of key factors providing means of identifying the potential role of parasitoids and predators in regulating the pest population. Their efforts were followed by Atwal and Singh (1974) on *Chilo partellus* a pest of maize, Bilapate et al. (1979) on *Helicoverpa armigera* on different food plants, on *Tryporyza nivella* (Roy
and Bains, 1983), *Metasyrphus corolla* (Sharma and Bhalla, 1992), *C. Septempunctata* (Singh et al., 1994) and *Spilosoma obliqua* (Rizvi and Pathak, 1998).

The fecundity of *Helicoverpa* in the range of 1000 to 2000 eggs is more common (Shanower et al., 1993). Studies on the innate capacity of increase in the number of *Helicoverpa armigera* were carried out by Patel and Koshiya (1999) at a constant temperature of 26±1°C on pigeon pea pods. An increment of the population with infinitesimal value of 0.1365 and finite rate of 1.147 females/female/day with a net reproductive rate of 427.94 was found which led to the completion of one generation in 46.06 days. In the previous years, i.e. in 1997 and 1998, they carried out the same experiment and at the same temperature of 26±1°C but on different hosts viz. Lucerne, Soybean, Sunflower and Pearl millet and computed the net reproduction rate of *H. armigera* as 206.35, 432.06, 489.23 and 374.01, respectively.

Sharma and Yadava (2000) found the net reproductive rate (R₀), mean length of generation (Tc), intrinsic rate of increase (e^m) ranged from 142.14 to 268.63, 39.12 to 45.22, 0.1180 to 0.1385, 1.125 to 1.148 and 2.565 to 3.016, respectively on different chickpea genotypes. The life table showing age specific survival (lₙ) and fecundity (mₓ) for female of *Helicoverpa armigera* revealed the shortest time span in immature stage in C-235 and longest in BG-1027, with respect to the check P-256.

Jallow and Matsumura (2001) investigated the effects of a range of constant temperatures (13.3- 32.5°C) on the development of all stages of *H.armigera* reared on tomato. A thermal constant of 51 degree-days above a threshold of 10.5 was required for the development of eggs. The larval stage required 215.1 degree-days and the pupal stage 151.8 degree-days above 11.3°C and 13.8 °C development thresholds, respectively.

Population density of *H. armigera* on rose flowers in central India indicated a maximum infestation level of (95%) with a pest density of 31 larvae/5 flowers during winter (Jan-Mar), and a minimum of 6% infested flowers with 4-5 larvae/5 flowers during summer (June-Aug) and 0 % infestation in November with the number of larvae linearly and significantly associated with flower infestation level, was advocated by Gahukar (2002).

According to Reddy et al. (2004) the age specific life tables for *H.armigera* on sunflower revealed that the period II (10 days after hatching) larvae are more
vulnerable to natural mortality factors, the highest survival rate being observed in the adult stage. The population doubling time (DT) was 6.107 days with a potential fecundity of 387.29 eggs.

Durairaj et al. (2005) discussed the intricate relationship between *H. armigera* and its host plants (i.e. cotton, pigeon pea and chickpea) and the effect of landscape patterns on the population dynamics of *H. armigera* in India.

ZengXiang (2005) studied the life table of the cotton bollworm, *Helicoverpa armigera* based on the demographic parameters, its population dynamics was simulated using Markov chain Monte Carlo method. The simulation results showed that cotton bollworm population dynamics was very complicated. Although original survived larvae were same, after several generations or life history stages, the population density of cotton bollworm varied enormously, ranging from slight occurrence to outbreak. The simulated results suggest that uncertainty exists in some extent to make long-term forecast of the bollworm dynamics.

A life table study of *H. armigera* was conducted on natural diet to know the successive age-intervals, rate of mortality, life expectancy etc on cotton by Jeyakumar et al. (2005). The percent mortality in big larvae (43.5%) was high followed by small larvae (41.3%), pupae (20.7%) and egg (14.0%). The mortality factors at different stages were identified as fungus, parasitism, NPV and unknown factors.

Sonawane et al. (2007) studied the life fecundity tables of *H. armigera* constructed on squares/bolls of *Bt* and non *Bt* cotton. In non *Bt* cotton, 75 adults and in *Bt* cotton, 8 adults emerged successfully from a cohort of 100 eggs. The net reproductive rate was 416.84, the finite rate of increase (X) was 1.1371 females per female per day, the mean generation time (T) was 46.58 days and intrinsic rate of natural increase (rm) was 0.1293. In *Bt* cotton, the net reproductive rate (Ro) was 47.05, which was very less as compared to non *Bt* Cotton. Life table studies showed that only 12 out of 100 larvae could manage to survive up to last instar and the adult emergence was restricted to nearly 8 per cent in *Bt* Cotton.

Song et al. (2007) conducted experiments to analyze the effect of adult feeding on the fecundity and oviposition pattern of moths, and larval performance. The results showed that the four traits viz total number of eggs, egg mass, egg hatch and female lifespan increased when the moths were fed with nutrients.
Acharya et al. (2007) studied the reproductive rate (Ro) of *Helicoverpa armigera* was 376.01 representing total female birth with a mean length of generation (Tc) 42.99 days was determined on cotton. The population increase with intrinsic rate of increase (rm) was 0.1379 and finite rate of increase (lambda) was 1.1489 females/female/day. On reaching stable age distribution, the population comprised mainly of immature stages and further life at the time of adult emergence, was reduced from 16.38 to 1.75 days.

Pandey and Tripathi (2008) examined development, survival, fecundity, progeny sex ratio (PSR) and age-specific life-table parameters of the parasitoid *Campoletis chlorideae* Uchida (Hymenoptera: Ichneumonidae) at six different constant temperatures (12, 17, 22, 27, 32 and 37 °C) in the laboratory [70% RH and 10:14 h (light:dark) photoperiod]. Second instar larvae of *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae) were reared on chickpea (*Cicer arietinum* L.) and used as the host. A reciprocal relationship between temperature and longevity was observed in the range of 12-17 °C. The maximum mortality of pupae (71.8%) occurred at 37 °C. The analyses of life-table parameters, developmental rates, reproduction, mortality and PSR suggest that maximum population growth is near 27 °C. There was little variation observed in most of the desired qualities of *C. chlorideae* in the range of 17-27 °C, and it appears that the parasitoid is adapted to a wide range of temperatures.

In a study by Naseri et al. (2009), the longest and shortest life expectancy (eₜ) of *Helicoverpa* was recorded to be 44.22 and 35.98 days on two soyabean cultivars Gorgan3 and BP when studied at 25±1°C with 65±5% RH and 16:8 (L:D) hour at the beginning of life.

**Management of Helicoverpa armigera**

During the ancient time, human had to live with and tolerate the ravages of insects and other pests but gradually he learned to improve his condition through trial and error experiences. Over the centuries farmers developed a numbers of mechanical, cultural, physical, biological and chemical control measures to minimize the damage caused by phytophagous insects. Chinese used chalk and wood ash for control of insect pest and arsenic to control garden pests (900AD). Saxena (2005) reviewed the current status on managing *H. armigera* in chickpea. The monitoring of
population, bio-ecology and control (using cultural, biological and chemical methods, resistant cultivars and plant extracts) of the gram pod borer were described.

Tomar et al. (2004) observed sequential sampling plans being essential in effective implementation of integrated pest management (IPM) of young larva of *H. armigera* in chickpea. In these studies, the larval population $d_2$ (upper critical limit) represent the economic threshold limits (ETL) when control measures become necessary. These ETL values are often first recorded at 50% flowering or pod initiation stage of the crop, when the larval population caused the maximum yield loss.

(a) Synthetic chemicals

From 1975 to 1985, the main insecticides used against *Helicoverpa armigera* were from Chlorinated hydrocarbons, Organophosphates, and Carbamate group like Carbaryl, Quinalphos, Monocrotophos, Methyl parathion, Fenthion and Endosulphan. During the mid-80’s synthetic pyrethroids namely Fenvalerate, Cypermethrin, and Deltamethrin were introduced which gave significant control of *H. armigera* and also augmented crop-yields. As a result of continuous harvesting of good yield, the farmers became liberal in use and as such resorted even up to 15-30 rounds of insecticidal application/season on cotton. This was the starting point of resistance development in *Helicoverpa* against most of the traditional insecticides in general and synthetic pyrethroids in particular. Management of *Helicoverpa* became more and more difficult. In the late 80’s pyrethroid resistance was relatively low at 3 to 11 folds in North India as against 6500 folds in the South. But later in 1992, high level of resistance in *Helicoverpa* was reported against pyrethroids in cotton and pulses and the consumption of pyrethroids dwindled after 2000. Fortunately, new insecticides belonging to different groups with their varied mode of actions like Indoxacarb, Spinosad, Emamectin benzoate were introduced during and after 2001 for *Helicoverpa* management in India. These molecules, because of their excellent control, changed the insecticide usage pattern against *Helicoverpa*. Pulses, being a rainfed crop showed good acceptance of Indoxacarb and Spinosad, by increasing their consumption during 2001-2004 and during this period there was a reduction of about 32 % in the consumption of generic molecules.
Singh and Sharma (2003) conducted an experiment to identify the effective chemicals for controlling *H. armigera* in chickpea cultivar Gaurav, under the dryland conditions of Jammu. The highest economic returns of Rs 13,771, 12,578, 11,800 and 11,543 were obtained in plots treated with Quinalphos, Endosulfan, Cypermethrin and Methyl Parathion, respectively. The highest cost: benefit ratio was obtained in plots treated with Methyl Parathion (1:13.7) followed by Endosulfan (1:11.8), Quinalphos (1:10.9) and Cypermethrin (1:8.1).

Shah *et al.* (2003) undertook a field study to compare the efficacy of cypermethrin 10 EC, endosulphan 35 EC, lambdacyhalothrin 2.5 EC and Chlorpyriphos 40 EC against the larval population of the gram pod borer in Faisalabad, Pakistan. They found chlorpyriphos as the most effective treatment with the extrapolated biomass of 56.34 kg/treatment and 14.20 kg grain yield/ treatment.

The use of insecticidal mixtures having either Cypermethrin or Alphamethrin with Chlorpyriphos or Quinalphos as their components could be best utilized to avoid or delay the development of resistance and the control of the pest under field conditions. Dhingra *et al.* (2003) had investigated mixtures of synthetic pyrethroids and organophosphates against the third instar larva of *H. armigera*. The LC$_{50}$ values revealed Ducord and Anaconda as the most toxic one among other mixtures viz. Nurelle, Virat, Nagata, Polytrin, Koranda and Spark. Yadava *et al.* (2003) determined the relative toxicity of four synthetic pyrethroids, viz cypermethrin, deltamethrin, fenvalerate, fluvalinate along with endosulfan by bioassay method against 1 to 2 days and 8-9 days old larvae of *H. armigera* using dry film technique. On the basis of LC 50 values, Deltamethrin was the most toxic one and endosulfan the least. The order of toxicity was found to be as: deltamethrin> cypermethrin> fluvalinate> fenvalerate> endosulfan. Baruah and Chauhan (1996) reported the order of toxicity against *H. armigera* as deltamethrin > cypermethrin > fenvalerate> endosulfan.

Ramasubramanian and Regupathy (2004) studied the pattern of cross-resistance in Lambdacyhalothrin and Betacyfluthrin selected populations of *Helicoverpa armigera* (Hub.) for fourteen consecutive generations that resulted in 2.58 and 3.01 fold increase in their susceptibility, respectively. Continuous selection enhanced the resistance level to the extent of 6.77 and 7.14 fold to the respective pyrethroids. The pattern of cross resistance studied in F$_9$ and F$_{14}$ generations revealed that the population selected for resistance to one pyrethroid extended resistance to
other four pyrethroids tested, probably due to the enhanced level of MFO-mediated mechanism. There was no cross resistance against Endosulfan because of differential site of action (picrotoxinin site, as of cyclodiienes) than that of pyrethroids (with voltage sensitive sodium channels as their site of action).

Geremew et al. (2004) evaluated four bioassay techniques for insecticide resistance monitoring in *H. armigera* (Lepidoptera: Noctuidae) to investigate resistance to the field rates of profenofos, endosulfan and lambdacyhalothrin using adult vial, topical application, square dip and larval immersion techniques. It was found that LD<sub>50</sub> values of lambdacyhalothrin in the third instar topical bioassay was 0.18 microg/g body weight, in the square dip test. Lambdacyhalothrin (Karate) was observed to yield 99.33% larval death at eight-times lower dose (6.25x10^-5 g a.i/ml) than the field rate. In larval immersion experiment lambdacyhalothrin gave 98.33% kills at eight-time lower dose.

Balikai (2005) evaluated some newer insecticidal formulations for their efficacy against the chickpea pod-borer. On spraying each treatment twice at 15 days interval commencing from 50% flowering, Cypermethrin 5+Acephate 45 DF at 400g a.i/ha with 14.3, 16.6 and 16.8% pod damage were found to be equally effective and gave 59.8, 53.4 and 52.8% protection to the crop against its borer. The highest seed yield of 10.0 q/ha was harnessed by Cypermethrin 5+Acephate 45 DF at 425 g a.i/ha with 88.7% increased yield over the untreated control.

Kathuria et al. (2005) had compared the toxicity of different insecticides against *H. armigera* and revealed a 46-fold resistance with Cypermethrin and 6- fold with endosulfan, respectively with Cypermethrin gaining a LC<sub>50</sub> value of 178.6 ppb and proving the most toxic one among Endosulfan, Fenvalerate, Quinalphos and Monocrotophos.

Murray et al. (2005) studied *Helicoverpa armigera* to the reduced efficacy of some older insecticide groups (pyrethroids and carbamates). Indoxacarb and spinosad at rates 50% or less of the registered rates for cotton were consistently superior to other tested products across the range of crops treated and provided residual protection for up to 14 days. The insect growth regulator compound, methoxyfenozide, was slower acting than other products tested, but demonstrated potential for *H. armigera* management.
Gehan et al. (2006) reported that the application of non-traditional compounds such as thiamethoxam (neonicotinoid group) or indoxacarb (oxadiozine group) significantly reduced the larval population of Helicoverpa armigera by 76% with methoxyfenozide (non-steroid ecdysone agonist) providing satisfactory control.

Ahmad (2008) unveiled the potentiation between pyrethroid and organophosphate insecticides in resistant field populations of cotton bollworm Helicoverpa armigera (Lepidoptera: Noctuidae) in Pakistan by using a leaf-dip bioassay. Chlorpyrifos potentiated lambda-cyhalothrin in one population but had an additive effect in the other. A strong potentiation of pyrethroids by ethion in some populations indicates that esteratic detoxification is a key mechanism involved in imparting resistance to pyrethroids in H. armigera.

(b) Botanicals

During the course of evolution, plants have developed effective counter measures to withstand the herbivores. Many classes of plant proteins and secondary plant substances have been shown to have toxic or antimetabolic effect on insects and have also been proposed as possible candidates for genetic engineering. A common feature of many of these compounds is that they have a chronic rather than an acute toxicity on insects and their effects are less dramatic than those of the synthetic insecticides. Retardation of insect development, slower rate of insect population growth and reduced fitness of surviving insects would allow a much wider window within which interventions can be successfully employed. This will help to generate greater confidence in the IPM among farmers, who normally prefer complete pest control based on chemical pesticides. Current attitudes in the world concerning food safety and environmental quality have raised the general public's interest in alternative (non-synthetic pesticide) pest control agents of plant origin. Botanical insecticides are naturally occurring insecticidal compounds derived from plants. They are processed into various forms which include:

- Preparations of crude plant material
- Plant extracts or resins, and
- Pure chemicals isolated from plants.
Botanical insecticides are promising alternatives for use in insect management. Plant species are rich sources of natural chemicals viz. alkaloids, phenolics, glucosinolates, which are also some secondary metabolites e.g. terpenoids, flavonoids, and acetogenins (Parmer and Devkumar, 1993) and several of them have shown to possess diverse biological effects on insect-pests. However, like conventional synthetic insecticides, botanicals have advantages and disadvantages and should be judged accordingly. The major bottlenecks being poor raw material base, lack of agro technology, high cost of collection and processing, product standardization etc which need to be tackled.

Simwat and Dhawan (1992) reported the insect growth regulatory effect and insecticidal property of Karanj oil against H. armigera. Apart from neem, various other plant species also show promising insecticidal properties. 15 acetogenins including annonin (squamocin), neoannonin and related 4 other acetogenins were found to be toxic against insects, when extracted from Custard apple (Annona squamosa) by Rao et al. (1999) and tested against Castor semilooper, Achoea janata and gram pod borer Helicoverpa armigera. Annona concentrate solvent based 2.5 EC @0.025% was effective antifeedant. The potential insecticidal activities of methanol extracts from 18 species of medicinal plants were tested against 3rd instar larvae of Egyptian cottonworm (Spodoptera littoris). All extracts were toxic and clear correlation existed between weight increase, quantity of ingested food, and the quantity of excrements pointing towards its antifeedant properties (Pavela and Chermenskaya, 2004). Neem, karanj and tobacco formulations were further tested by mixing in the semi-synthetic diet at the time of compounding and their morphogenetic effects on 3-day-old larvae of H. armigera. The treatments of diets with benzene extract (0.2%), chloroform extract (0.025%), ethyl acetate, methanol, and butanol extracts (0.05% and 0.2%), neem seed kernel extract 6-10%, Green mark and neem guard 0.4-0.8%, neem oil 2-6%, Karanj oil 6% and nicotine sulphate 0.3-0.4% resulted in 100% mortality in different developmental periods. The maximum larval duration 28.9 days with minimum pupal weight 145.6 mg was observed with methanol extract at 0.025 % (Bajpai and Sehgal, 2003). The same year they also tested their oviposition behavior at Pantnagar, and showed that methanol and chloroform extracts of neem seed kernel and nicotine sulphate were very effective
whereas water extract of neem oil was effective only at higher concentration (Bajpai and Sehgal, 2003)

Kaushik and Kathuria (2005) observed growth inhibition, prevention of molting, production of smaller larvae and reduced number of pupal emergence in the larvae fed with mustard cake powder. The larval weight on the 7th day was 4.5, 2.3 and 6.3 mg with mustard cake powder, neem oil and neem cake treatment, respectively as against 110 mg in control, with significant mortality counts at pupal stage. Kaushik and Kathuria (2005) further evaluated the crude leaf extracts of *Eucalyptus camaldulensis* and *Tylophora indica* for their antifeedency against *Helicoverpa armigera*. The methanol extracts inhibit feeding the most, the ethanol extracts reduce by 50% with EI50 of 6.9% for *E.camaldulensis* and 2.8% for *Tylophora indica*. They advocated crude alkaloids from *T. indica* and crude tannins from *E.camaldulensis* to be potent in reducing the larval feedings.

Botanical pest control is a distinct possibility in the subtropical countries which are endowed with the bio-diversity of such plants. Reena and Singh (2007) screened the biology of *H. armigera* by the extracts and fractions of *Pongamia pinnata* seeds (both mature and immature) by pod dip and spray method. As for result, mature seeds proved better in altering the biology and the increase or decrease was in a dose-depended manner. 2% mature seed hexane fraction proved the best and immature seed acetone fraction (0.5%) was the least effective one and was on par with control. The male female ratio did not follow any set pattern. Reduction was more when they were sprayed on to the larvae thus proving their contact action. Morale et al. (2000) noted prolonged larval and pupal period when fed on karanj oil (1%) treated cotton.

The insecticidal and biological activity of Rhizomes of ginger (*Zingeber officinale*) on *H. armigera* was investigated by Singh et al. (2006) on cotton balls treated with its methanol extract and its fractions. Its adverse effects on larval duration (12-18.33 days), larval weight (302-492 mg), pupation, adult emergence and larval mortality, consumption and utilization efficacy and food deterrence effect was revealed. The saponin and methanol extract of *M. indica* was more effective to cause percent antifeedency (AI 50 value=7.14%), larval growth inhibition and inhibition of normal adult development against *H. armigera* than hexane and aqueous extracts, as reported by Loganathan et al. (2006).
Botanicals under present study and their medicinal backgrounds

*Mucuna cochinchinensis* or velvet bean is an annual climbing vine that grows 3-18 m in height and is indigeneous to tropical regions especially Africa, India and the Indies. This plant belongs to Fabaceae family and produces the cluster of mucuna beans. Ambasta (1986) reported that the related species such as *M. pruriens* and *M. bracteta* possessed some insecticidal properties. It is a constituent of more than 200 indigenous drug formulations (Murthy and Mishra, 2009) involving β-sitosterol as the most prevalent phytosterols. The seed pods of *Mucuna pruriens* are covered with reddish hairs that are easily dislodged and can cause severe skin irritation. These stinging hairs of seed pods contain the phytochemical mucunain which cause the irritation. The main phytochemicals present in velvet bean includes alkaliyl alkylamines, arachidic acid, behenic acid, betacarboline, sitosterol, bufotenin, cysteine, dopamine, fatty acids, gallic acid, genistein, glutamic acid, glutathione, histidine, isoleucine, lysine, oleic acids, mannose, mucunadine, nicotine, serotonin, stearic acid, riboflavin, threonine, trypsin, valine, tyrosin, valine and vernolic acid. Traditionally velvet bean has been used as nerve tonic for nervous system disorders. The phytochemical study of the seeds of another species *Mucuna monosperma* DC revealed the presence of flavonoids, steroids and triterpenoids and the compounds acacetin, luteolin, b-sitosterol, stimasterol, ursolic acid and betulinic acid (Mallaiah et al., 2008). Mohan et al. (1995) also reported the presence of amino acids viz. isoleucine, tyrosine and phenyl alanine in this genus. Almost all parts of the plant are reported to contain L-3,4-dihydroxy phenylalanine (L-Dopa), a non-protein amino acid that acts as precursor for the neurotransmitter dopamine (Vibha et al., 2009).

*Crataegus crenuleata* (Syn. *Pyracantha crenuleata*) is an ornamental shrub or small tree, distributed in Himalayas in dry localities, from Kashmir to Bhutan (excluding Sikkim), alt-700-2400 m. It is a member of Maloideae family and is reported to be astringent, sedative, cardiotonic, diuretic, stomachic and antispasmodic. The extract of leaves, flower and fruits containing flavonoids showed inhibitory effect on activity of guinea pig heart phosphodiesterase. The young leaves are used as a substitute for tobacco. The leaves contain Vitexin-4'-RHamnoside, vitexin, quercetin, hyperoside, dimeric leucoantho-cynidide and epi-catechin and triterpene acids. *Crataegus crenuleata* contains Pyracrenic acid named as 3B (3, 4-
dihydroxycinnamoyl)-oxylup-20(29)-en-oic acid. The acid exhibited anti-inflammatory activity by the formation of granulated tissue.

*Peltophorum vogelianum* also belongs to the family Fabaceae, subfamily caeselpinioideae, of the order Fabales and class Magnoliopsida. It is a deciduous tree growing to 15-25 m tall, with a trunk diameter of up to 1 m. The leaves are bipinnate, 30-6- cm long, with 16-20 pinnae, each pinna with 20-40 oval leaflets. The flowers are yellow, 2.5-4 cm diameter, produced in large compound racemes upto 20 cm long. The fruit is a pod 5-10 cm long and 2.5 cm broad, red at first, ripening black and containing one to four seeds. Trees begin to flower after about four years. Members of this family have medicinal or insecticidal properties. For instance residue of *Derris* has insecticidal and pesticidal properties, and its leaves, flowers, bark, seeds, and sap has medicinal properties. The gum of *Peltophorum africanum* is reputed to be poisonous. Its bark is chewed to relieve colic and a variety of stomach disorders such as diarrhoea and dysentery and to get rid of intestinal parasites. Steam from a hot bark decoction is applied to sore eyes and, in serious cases, it is dropped into the eyes. The powdered decorticicated root is applied to wounds to hasten healing, and a decoction is taken by mouth or gargled to treat sores in the throat. The roots are also boiled in water and used as an enema. Leaves are boiled and the steam directed into the mouth to relieve toothache. The bark of *Peltophorum pterocarpum* can be used in the fermentation of palm wine and it also has medicinal properties though it serves as a host for lac insects. (ECOCROP.)

Rubiaceae is the coffee family which is the fourth largest angiosperm family and comprises nearly 650 genera and 13000 species (Delprete, 2004 and Govaerts *et al.*, 2006) dwelling in almost all habitats. These species included trees, shrubs, lianas and herbs with the characteristic stipules and inferior ovules. Cyclotides, which are disulfide rich peptides or mini-proteins with the unique structural feature of head to tail cyclized backbone and a knotted arrangement of three-disulfide bond, called as cyclic cystine knot (CCK) motif (Craik *et al.*, 1999), are reported to occur in 22 species of Rubiaceae family with 3700 species potentially containing cyclotides (Gruber *et al.*, 2008). *Anthocephalus cadamba* is also included in this study which belongs to the rubiaceae family. The partially purified extracts of *Anthocephalus cadamba* showed good bioefficacy in terms of adulticidal, ovicidal, and ovipositional deterrent activities against *Callosobruchus chinensis* (Prakash *et al.*, 2008). Sahu *et*
al. (2000) isolated two triterpene glycosides from the bark of cadamba defined as glycoside A (3-O-[(α-L-Rhamnopyranosyl)-quinovic acid-28-O-[(β-D-glucopyranosyl] ester and glycoside B (3-O-[(β-D-Rhamnopyranosyl]-quinovic acid-28-O-[(β-D-glucopyranosyl] ester respectively. Earlier the pentacyclic triterpenic cadambagenic acid i.e. 18α-olean-12-en-3β-ol-27,28-dioic acid was isolated by Sahu (1974) from its bark. Bahadur et al. (1966) listed a number of essential oils from A. cadamba as linalool, geraniol, geranyl acetate, linalyl acetate, camphene, myrcene, β-phellandrene, terpinol, p-cymol, 2-nonanol, α-bergamottin, α-selinene, curcumene and some unidentified fractions. Agusta et al. (1998) extracted the chemical composition of its bark by maceration in a methanol-chloroform mixture (1:1) followed by evaporation, which on further separation with hexane, chloroform, ethyl acetate and methanol yielded the steroids as sitostenone, 3β-ergost-5-en-3-ol, γ-sitosterol, stigmasterol and 4, 22-cholestadiene-3-one and β-sitosterol.

The genus *Xylosma longifolium* is a large genus of shrubs and trees is chiefly distributed in most of the tropical and subtropical region. About four species occur in India. The *Xylosma* species are reported to possess medicinal properties such as *Xylosma japonica* is used to heal jaundice, serofula, sore and tumours, as desulfurizing agent and as a deminozide agent. *Xylosma longifolium* commonly known as khandhara is found to resemble opium in its action and is used with it for house pests and fences. Medical importance of *X. longifolium* prompted us to carry out the comprehensive investigation of the leaves of *X. longifolium*. The secondary metabolites from *Xylosma* species include benzoylated phenolic glucosides e.g. xylosmacin, xylosmin and poliothyrsoside, catchol, syringing, salirepin, tachioside and the newly reported RHyncoside. (Ren Xu et al., 2008) from *X. controversum*. Further from *X. flexuosum*, glycosides reported were salireposide, polipthrysoside and 2’ benzoylpoliothyrsoside (Gibbons et al., 1995).

Asparagaceae is a monogenic family, which was previously included in the Liliaceae, comprising of 100 species (w3-TRO-PICOS,2000) and includes herbs, shrubs and vines widespread in the Old world. *Asparagus falcantus*, in our study withholds this family. The extract of *A. falcantus* possessed a high biological activity relative to the level of RIA (Radio immunoassay) positive material being mixtures of the parent ecdysteroid (20E or PonA) and a co-eluting conjugate (Dinan et al., 2001).

(c) Biopesticides and Natural enemies
1. Biopesticides

Mistry et al. (1984) reported that five sprays of HaNPV @ 250 LE/ha has given control of this pest on chickpea. Similarly, among different doses, the highest test dose of $1.5 \times 10^{12}$ POB/ha has proved to be the best in reducing the pest population and increasing the marketable yield of tomato. Treatment of chickpea with HearNPV at $1.5 \times 10^{12}$ p.i.b/ha was as effective at controlling *H. armigera* larvae and increasing yield with respect to endosulfan or *Bacillus thuringiensis* as control as reported by Cherry et al. (2000). Greenhouse experiment was conducted by Sireesha and Kulkarni (2002) to know the efficacy of different NPV formulations @ $2.4 \times 10^7$ against 2nd instar *H. armigera* larvae on sunflower. Oil formulations @ $2.4 \times 10^7$ POB/ml were found significantly more effective than aqueous (@ $2.4 \times 10^7$ POB/ml) wettable powder (@ $6 \times 10^8$ POB/g) and dust formulations (@ $6 \times 10^7$ POB/g).

Kalia and Chaudhari (2004) investigated the baculovirus infection of the American bollworm through the tracheal system. Topical application of HaNPV dissolved in alkaline solution did not encounter maturation immunity that is associated with oral inoculation immunity. The incubation period was reduced to 2-3 days when HaNPV suspensions were applied to thoracic spiracles as against 5 days in oral inoculations, marking the rapid spread of the virus infection.

Joshi et al. (2006) evaluated HaNPV for the management of the pod borer against tomato and found that the highest test dose of $1.5 \times 10^{12}$ POB/ha proved the best in reducing the pest population, yielding a highest marketable yield of 101.25 q/ha of tomato.

Mehrvar et al. (2007) studied the stability of crude and semi-purified extracts of NPV isolates of *Helicoverpa armigera* under simulated sunlight as under the UV light of 280-400 mm. The percent larval mortality of *Helicoverpa armigera* larvae due to crude extracts of all isolates was significantly higher than semi-purified extracts. Larval body fluid and debris in the crude extracts of the isolates probably acted as a UV protectant and increased the larval mortality in significant proportions. So, retention of some quantity of larval debris in the formulation, in fact, enhances the activity of virus on host plants.

Shankar et al. (1992) evaluated Biobit (*Bacillus thuringiensis* var *kusrtaki*) against *Helicoverpa armigera* in pigeonpea and found that biobit @ 1 kg/ha was as
good as Cypermethrin (0.02 %) and the doses of 1 and 1.5 kg/ha were encouraging in checking pod borer damage. Balasubramanian et al. (2002) compared the efficacy of *Bacillus thuringiensis var galleriae* (Spicturin) with cartap against the pod borer in chickpea and found significant reduction in the larval population with Spicturin @ 2 lit/ha followed by Cartap 50 % SP @ 2.5 kg/ha. Chandrashekhar et al. (2005) reported the baseline susceptibility of *H. armigera* against the toxicity of Bt and its Cry toxins in relation with temperature regime and insect acclimation. It was revealed that an increase in ambient temperature (about 10 °C) increased the susceptibility to *Bacillus thuringiensis var kurstaki* HD-73 by 7.5 fold.

Lawo et al. (2008) used genetically modified (*Bt*) crops expressing lepidopteran-specific Cry proteins derived from the soil bacterium *Bacillus thuringiensis*. Bioassays were conducted to understand the interactions between a Cry2Aa-expressing chickpea line, either a susceptible or a Cry2A-resistant *H. armigera* strain, and the entomopathogenic fungus *Metarhizium anisopliae*. Resistance to Cry2A did not cause any fitness costs that became visible as increased susceptibility to the fungus. On *Bt* chickpea leaves, susceptible *H. armigera* larvae were more sensitive to *M. anisopliae* than on control leaves. It appeared that sublethal damage induced by the *B. thuringiensis* toxin enhanced the effectiveness of *M. anisopliae*. For Cry2A-resistant larvae, the mortalities caused by the fungus were similar when they were fed either food source. The findings suggest that *Bt* chickpeas and *M. anisopliae* are compatible to control *H. armigera*.

2. Natural enemies

Mansfield et al. (2003) studied the impact of ant predation of *Helicoverpa armigera* population in cotton crops. The predation rate by *Pheidole* species was approximately 10 times greater than by *Iridomyrmex* species, *Paratrechina* species and *R. metallic* did not prey upon. Extrapolation of data to 24 hour suggests a rate of approx 3% eggs /24 hrs for *Pheidole* species and less than 1% eggs/24 hrs for *Iridomyrmex* species.

Kulat et al. (1999) investigated the feasibility of using *Trichogramma chilonis* Ishii by mass-release method to control *H. armigera* infesting chickpea. It was revealed that none of the 1763 eggs collected during the growing seasons of 1994-
96 from chickpea was parasitized. Shirazi (2007) studied the developmental period of the female progeny of *T. chilonis* and found it to be shorter on eggs of its factitious host *Corcyra cephalonica* as compared to its natural host *Helicoverpa armigera*. The number of male progeny emerged was higher on *C. cephalonica* eggs though number of malformed male progeny was significantly higher on *H. armigera* eggs.

Bisane *et al.* (2008) also reported the parasitization of larvae and pupae of *Helicoverpa armigera* (Hubner) on cotton. *Bracon sp.* was noticed from 37th to 41st MW to the extent of 10.53% (37th MW) and *Chelonus sp.* started their activity from 38th to 40th MW with maximum in 39th MW (6.06%). These parasitoids contributed near about two-thirds of total mortality of early instar larvae. Further, they found the parasitization of *H. armigera* (Hubner) on pigeonpea by the ichneumonid, *Campoletis chlorideae* to be active in December (16.67 per cent) and parasitism by a Braconid, *Bracon sp.*, noticed from 45th to 47th MW and 50th MW, was up to an extent of 7.89 per cent.

Bhat *et al.* (2009) recorded 8 Hymenopteran and 1 Dipteran parasitoids and 3 insect predators as the natural enemies of *H. armigera* from Kashmir Valley. Out of these, *Campoletis chlorideae, Diadegma fenestralis* [*Diadegma fenestrale*], *Charops bicolor, Euplectrus euplexae*, and *Microplitis sp.* and *Eriborus sp.* are thought to be new records of *H. armigera* parasitoids from Kashmir Valley.

### 3. Combination products

As botanical preparation and microbials are fast replacing synthetic insecticides, there’s an increasing tendency among farmers to mix them up to strengthen the prospects of biocontrol. The influence of host plant resistance on the efficacy of NPV and quinalphos as mortality factors in *H.armigera* populations on chickpea was examined by Cowgill and Bhagwat (1995) who found independent relationship between all the three factors. Bioefficacy of *B.t* products namely Delfin (*B.t.var kurstaki*), Spicturin (*B.t.var galleriae*) and Agree (*B.t.var kurstaki+aizawai*), each at 1%, in combination with botanicals were checked by Venkadasubramanian and David (1999) against *Helicoverpa armigera* and *Spodoptera litura*. *Bt* products
were significantly inferior to palmarosa oil which caused 91.2% mortality of *H. armigera* larvae. In combinations, delfin + palmarosa oil recorded the highest mortality of 96.48%.

Biocides and their combinations were effective in reducing the larval populations next only to chlorpyriphos @1.00 l/ha by Loganathan *et al.* (2000) which recorded the lowest larval population of *Helicoverpa armigera*, followed by (the indigenous liquid) *Bacillus thuringiensis* var *galleriae*, Spicturin @ 2.00 l/ha + HaNPV and Spicturin @ 1.50 l/ha + HaNPV three days after each application. The cost benefit ratio was higher in chlorpyriphos 1.00 l/ha (1:3.50) followed by HaNPV @ $1.5 \times 10^{12}$ POB/ha individually (1:3.32), Spicturin @ 1.00 l/ha (1:2.18) and Spicturin @ 1.00 l/ha + HaNPV (1:2.07).

Bhatt and Patel (2002) evaluated bio-pesticides viz. *Bt*, NPV and botanicals (neembicidine, tobacco snuff decoction) alone and in combination with insecticides (Fenvalerate, Endosulfan, monocrotophos). They found Endosulfan 0.035% + HaNPV 250 LE/ha, Fenvalerate 0.005% + HaNPV 250 LE/ha and Endosulfan alone superior from the rest treatments.

Gowda *et al.* (2004) compared biointensive and pesticide-based IPM modules with the untreated control to evaluate the effects of different integrated pest management (IPM) practices and intercropping systems on the pod borer (*H. armigera*) of chickpea. Intercropping of chickpea with safflower, especially in a 6:1 ratio, reduced pod damage and increased chickpea yield compared with the chickpea-wheat system.

Nath and Chakravorty (2004) evaluated the efficacy of nimbecidine (*Azadirachta indica* formulation) (0.2%), RD 9 Repelin (*A. indica* formulation) (1.0%), NSKE (neem seed kernel extract) (5.0%), *Bacillus thuringiensis* subsp. *kurstaki* formulations Biobit (1.5 kg/ha) and Delfin (2 kg/ha), HaNPV (*H. armigera* nuclear polyhedrosis virus) (250 LE) and endosulfan (Thiodan 0.07%) against *H. armigera* infesting chickpea. Two sprays each of HaNPV and endosulfan resulted in the lowest population of *H. armigera* (0.55/m row length, on average). The lowest average levels of pod (6.17%) and seed (9.10%) damage, and the highest average yield (18.92 quintal/ha) were obtained with 2 sprays of endosulfan.
Balakrishnan et al. (2004) studied the efficacy of *Trichogramma chilonis* Ishii in combination with some biopesticides viz *HaNPV*, *Bt* var *kurstaki* (Halt WP) and *Beauveria bassiana*, which revealed that two releases of *T. chilonis* (6.25 cc/ha) at 45 and 60 DAS with two sprays of *B. t k* @kg/ha, 90 and 120 DAS recorded the highest yield with least damage on squares, bolls and loculi in rainfed cotton ecosystem.

Singh and Ali (2005) conducted a study during rabi 1999-2000 and 2000-01 at Faizabad, Uttar Pradesh to evaluate the efficacy of *Helicoverpa armigera* nuclear polyhedrosis virus (*HaNPV*) at 250, 350 and 450 LE/ha, *Bacillus thuringiensis* (Bt) at 1%, neem seed kernel extract (NSKE) at 5% and endosulfan at 0.07% against *H. armigera* infesting chickpea cv. K-850. Maximum larval mortality was recorded in endosulfan (85%), followed by *Bt* formulation (80%) and *HaNPV* at 450 LE/ha (75%). NSKE was the least effective treatment. The highest yield was obtained in endosulfan (25 q/ha), followed by *HaNPV* at 450 LE/ha (23.66 q/ha) and *Bt* 1% (24 q/ha).

Kambrekar and Kulkarni (2005) evaluated five isolates of nuclear polyhedrosis virus of *Helicoverpa armigera* (Hubner) (*HaNPV*) under field conditions. The least pod damage (8.26%) was recorded in the recommended control (RC) comprising four fortnightly sprays, starting 30 days after sowing, with profenofos (Curacron 50EC; 2 ml/litre) followed by neem seed kernel extract (NSKE) 5%, *HaNPV* (250LE/ha) and monocrotophos (Monocil 36SL; 1.25 ml/litre).

Kulkarni et al. (2005) further evaluated different biopesticides against *Helicoverpa armigera* on chickpea cv. ICCV-2. Treatments comprised: *Beauveria bassiana* (0.5, 1.0 and 1.5 g/litre), *Bacillus thuringiensis* (Bt), *Nomuraea rileyi* (0.5, 1.0 and 1.5 g/litre), *Metarhizium anisopliae*, nuclear polyhedrosis virus (NPV), 5% neem seed kernel extract (NSKE) and 1 ml monocrotophos/litre. Among the biopesticides, NPV recorded the highest grain yield (8.25 q/ha), followed by *N. rileyi* (7.44 q/ha) and *M. anisopliae* (7.42 q/ha), while *M. anisopliae* recorded the lowest pod damage (18.06%), followed by *N. rileyi* (18.64%) and NPV (20.07%).

Sachan et al. (2005) conducted a field experiment during rabi 2002-03, at Bareilly, Uttar Pradesh, to evaluate the efficacy of nuclear polyhedrosis virus (NPV) against *H. armigera* on chickpea cv. Pusa 256. NPV + monocrotophos was identified
as the best treatment, with the lowest pod damage (6.20%) as well as the highest pod yield (20.50 q/ha), with a net profit Rs 14 115/ha and benefit:cost ratio of 6.8.

Gowda and Yelshetty (2005) carried out a field studies using commercial formulations of microbial agents (bacteria, fungi and virus) for the management of *H. armigera* on chickpea (*Cicer arietinum*) cv. Annigeri-1. *Bacillus thuringiensis* (*Bt*) formulations (Delfin at 1500 g, Biolep at 1500 g, Halt at 2000 g and *Bt* var. *kenyae* at 1500 g/ha), *Ha* nuclear polyhedrosis virus (*HaNPV*; at 250 LE/ha) and *Beauveria bassiana* (Dispel L at 5000 ml and Basina at 5000 g/ha) were tested in replicated trials and the results were compared with that of the untreated control and endosulfan 35 EC (at 1000 ml/ha) by recording pod damage and grain yield. The percentage pod damage did not vary among the treatments. The highest grain yield of 10.36 q/ha was recorded in *HaNPV* -treated plots followed by *Bt* var. *kenyae* (9.40 q/ha) and Halt (8.70 q/ha).

Prabhuraj et al. (2005) conducted a field experiment at Raichur, Karnataka, to evaluate the effect of *Heterorhabditis indica* in combination with other entomopathogens and botanicals against *H. armigera* (Hubner) in chickpea ecosystem. Pooled data on per cent larval reduction after two sprays revealed that the highest reduction of 47.63% was achieved in chlorpyrifos/quinalphos (0.04/0.05%) treatment at seven days after spraying. However, sequential application of *H. indica*+*Pongamia pinnata* (1.0 lakh IJs+2.5%) and *H. indica*+*Prosopis juliflora* (1.0 lakh IJs+10%) recorded maximum yield (1.96 and 1.83 kg/plot, respectively) with minimum pod damage (10.9 and 11.5%, respectively). Thus, there is a scope for integration of *H. indica* with *Pongamia pinnata* and *Prosopis juliflora* for the effective management of chickpea pod borer.

Visalakshmi et al. (2005) carried out an investigation on the effect of various integrated pest management (IPM) components on *H. armigera* and their impact on natural enemies present in chickpea during 1998-2000 cropping seasons in Patancheru, Andhra Pradesh. Application of neem effectively reduced the oviposition by *H. armigera* throughout the cropping period. The integration of various IPM components was found to be the best in reducing the pod damage (10.4%) with highest grain yield (1264.4 kg/ha) with 58.5% increase in yield over control (797.9 kg/ha). The highest cost-benefit ratio (1:3.01) was obtained in plots treated with IPM.
Verma and Lal (2006) advocated that bioproducts (i.e., plant extracts *Aloe barbadensis* and *Nicotiana tabacum* and whey) when considered singly, were comparatively much less effective, while the combination of whey/lassi + *Aloe barbadensis* + *Nicotiana tabacum* was quite effective, perhaps due to their synergistic effect for which behaved closer to endosulfan (0.005%) in efficacy.

Singh *et al.* (2006) also tried different modules of integrated pest management (IPM). Among the modules tested, the 3 sprays of endosulfan was found the most effective in controlling gram pod borer (6.83% pod damage), resulting in the maximum grain yield (2489 kg/ha). This was followed by the module of neem oil-HaNPV-endosulfan (7.92% pod damage and 2267 kg/ha yield). The cost benefit ratio (CBR) varied from 0.17 to 6.97. The spray of neem oil and HaNPV alternated with endosulfan was also found effective against the pest with a CBR of 1:2.92.

Singh and Yadava (2006) assessed the efficacy of ten treatments comprising of three modern insecticides viz indoxacarb, spinosad and carbosulfan, one conventional insecticide (Endosulfan), two Bt based biopesticides (Halt and Biolep) and three neem based formulations (Nimbicidine, Neemarine and Achook) against the pod-borer in pigeonpea. The study revealed that indoxacarb gave the best result among all the treatments with 5.20% pod damage and 1435.55 kg/ha grain yield. Among biopesticides, Halt was found superior to Biolep and significantly superior to neem based formulations. The crop sprayed with Halt received 24.23 percent grain yield. Among neem family, nimbicidine received highest percent yield increase over control i.e. 85.88%. The maximum profit was received from Indoxacarb which gave a benefit of Rs. 18.82 against investment of one rupee.

Bhalkare *et al.* (2007) determined the cost-effective combinations of microbial insecticides (*H. armigera* nuclear polyhedrosis virus or HaNPV and *Bacillus thuringiensis* subsp. *kurstaki*), plant product (neem seed extract), and reduced insecticide rate for the management of *H. armigera* on chickpea (cv. Chaffia). Pooled data on percent larval reduction after the second spray revealed that HaNPV alternated with endosulfan (0.07%) at 15 days after spraying (92.61% larval reduction) and mixed spraying of HaNPV with 50% of the recommended rate of endosulfan (88.16%) recorded the highest grain yields (18.47 and 17.97 quintal/ha, respectively) and HaNPV alternated with endosulfan (0.07%) registered a cost benefit ratio of 1:10.14.
Gupta et al. (2007) studied three strains of NPV, isolated from infected larvae of host insects and compared the pathogenicity/speed of kill of various isolates in term of median Lethal Dose (LD$_{50}$) and median Lethal Time (LT$_{50}$) in a bioassay by diet plug method to select a candidate isolate for field potential in tomato and chickpea against *H. armigera*. The candidate virus was found compatible with the recommended insecticide endosulfan, *Bacillus thuringiensis* and egg parasitoid, *Trichogramma pretiosum* in combined as well as sequential manner.

Among neem oil, citronella oil, karanj oil, cottonseed oil and sesamum oil, B.t.k 0.2% + neem oil 5% recorded the highest feeding inhibition in *Spodoptera litura* reared on Castor leaves, as reported by Babu et al. (2007).

Gupta (2007) carried out a study on chickpea (*Cicer arietinum* cv. JG-322) to find out the efficacy of indigenous products against the incidence of gram pod borer, *H. armigera*. The results revealed that indigenous products, garlic+red pepper (0.5, 1.0%), cow butter milk (4-8%), buffalo butter milk (8%) and biological insecticide, *Bacillus thuringiensis* (0.2%) were highly effective and statistically at par with chemical pesticides quinalphos (0.05%) and cypermethrin (0.01%). The incremental cost benefit ratio was highest with garlic+red pepper extract -0.5% (19-4) and cow butter milk 4% (19.3).

Sharma et al. (2007) conducted demonstration and validation of the IPM-module for *H.armigera* and effectiveness of different components, namely HaNPV alone, HaNPV + endosulfan, endosulfan alone, neem extract, intercrop effect on eggs and larvae of *H. armigera* including floral and pod damage, compared to that of farmer's practice (FP). IPM plots yielded significantly higher (17.4 q/ha) than FP (9.89 q/ha). Cost-benefit ratio was also quite favourable in IPM (1:4.79) compared to that of FP (1:2.37). The economics of grain yield revealed that cultivation of coriander as intercrop was the best treatment with the highest yield (1.17 t/ha) and cost:benefit ratio (CBR) of 1:6.3 followed by application of endosulfan alone resulting in an yield of 1.05 t/ha and CBR of 1:6.1.

Tiwari and Sehgal (2007) evaluated the field efficacy of insecticides (endosulfan, monocrotophos, cypermethrin, deltamethrin and fenvalerate) individually and in combination with *Bacillus thuringiensis* var *kurstaki* (Bt) Berliner on *H. armigera*. The chickpea crop was sprayed twice in both the years with the
respective insecticides when pest population exceeded the economic threshold level. Among the tested chemicals, cypermethrin+Bt var kurstaki, cypermethrin, deltamethrin+Bt var kurstaki and Bt var kurstaki were found significantly superior over rest of the treatments and two years data clearly showed that insecticides in combination with Bt var kurstaki were found highly effective in increase in grain yield and in reducing larval population and pod borer damage.

The pesticidal properties of the plant extracts of Parthenium hysterophorus was compared with Biovirus H™ (HaNPV) by Ullah et al. (2007) and at similar concentrations HaNPV ranked higher in rate of mortality but the botanical was cheaper and thus recommended as an IPM tool.

Pandey and Ujagir (2008) conducted a field trial to determine the effect of coriander, linseed and barley as intercrops in chickpea on H. armigera incidence and yield. In general, all the three intercrops were found to be effective in reducing the egg count and larval population. Overall, mean number of egg count varied from minimum of 17/m² in chickpea+coriander (2:1) and chickpea+barley (4:2) to the maximum of 37.7/ m² in chickpea sole crop. The reducing effect of intercropping on egg count was more pronounced when chickpea and coriander were grown at the row ratio of 2:1. This suggested that both egg and larval counts of H. armigera could significantly be reduced if chickpea was intercropped with coriander at 2:1 ratio. The highest pod borer damage (90.6%) was recorded in chickpea sole crop, which was significantly suppressed with the introduction of intercrops. Mean equivalent grain yield in intercropping combinations ranged from maximum of 886.8 kg/ha in chickpea+coriander (4:2) to minimum of 188.9 kg/ha in chickpea sole crop.

Prasad et al. (2008) found the efficacy of test insecticides in the order: oxydemeton methyl (0.06%) > NSKE (5%) > neem oil (2.5%) > Vanguard (2.5%) > neembecidine (2.5%) > karanj oil (3%) > Achook (2%) in terms of reducing the incidence of Dasyneura lini and H. armigera.

Gowda et al. (2008) conducted a field study for evaluation of different IPM modules for the management of pod borer, using tolerant (ICC 506) and susceptible (Annigeri 1) genotypes. The results indicated significantly higher number of good and total pods, and lower number of damaged pods and percent pod damage in ICC 506 than Annigeri 1.
Kale et al. (2008) evaluated the efficacy of chemical and biological control treatments against *H. armigera* on cowpea (cv. Chaffa). The treatments consisted of: *Bacillus thuringiensis* subsp. *kurstaki* (*Btk*; 2x10^8 spores/ml) at 750 ml/ha + *H. armigera* nuclear polyhedrosis virus [HaNPV; 2x10^9 POB (polyhedral occlusion bodies)/ha] at 250 LE/ha (S1); *Btk* at 750 ml/ha (S2); *Btk* at 750 ml/ha + *HaNPV* at 250 LE/ha + endosulfan at 0.06% (S3); endosulfan at 0.06% + *Btk* at 750 ml/ha + *HaNPV* at 250 LE/ha (S4); neem seed kernel extract at 5% + *Btk* at 750 ml/ha + *HaNPV* at 250 LE/ha (S5); *Btk* at 750 ml/ha + *HaNPV* at 250 LE/ha + spinosad at 50 g a.i./ha (S6); spinosad at 50 g a.i./ha + *Btk* at 750 ml/ha + *HaNPV* at 250 LE/ha (S7); and untreated control (S8). Endosulfan (control) and S5 recorded the lowest cumulative average larval population and highest grain yield.

Wakil et al. (2008) tried to set up trends in integrated pest management strategies for the control of *H. armigera* on chickpea and found that the application of Steward proved most effective when applied alone, with 0.41 larvae/plant, pod infestation of 9.31% and the highest grain yield (1203.66 g/plot) however the further integration of weeding and hand picking reduced the larval population (0.12 larvae/plant) with minimum pod infestation (5.45%) on variety CM-2000 and resulted in the maximum yield of 1260.33g/plot. The cost benefit ratio with Steward alone was 1:2.20 and with impregnation of weeding and hand picking, it rose to 1:3.53.