Chapter II

REVIEW OF LITERATURE
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The true cotton belongs to genus *Gossypium* of family malvaceae. Thirty one species of *Gossypium* have been recorded in the world. Of these twenty seven are wild and four cultivated. Amongst cultivated species *desi* cotton (*G. arboreum* and *G. herbaceum*) are distributed throughout Africa and Asia and are termed as "Old world contingens". The new world contingens, *G. hirsutum* and *G. barbadense* are the natives of Western Hemisphere (Fryxell, 1969).

2.1 History of cotton in India

He one know when man first used cotton as a textile fibre. Cotton fabrics dating back to about 3000 B.C. were found in excavations in the Indus river valley. According to Manu, the Hindus have known cotton for textile since 800 B.C. However, systematic cultivation of cotton did not begin until the immigration of Europeans. In the 14th century Arab traders imported cotton goods from India via the Levant to Vanice. Export of cotton to England was first made in 1430.

In 1840, varieties of American cotton *hirsutum* types with long and fine quality fibre were brought to
India. Though desi cottons are tolerant to insect pests, yet are poor yielders and also possess poor quality fibre. Therefore, due to high yields and quality in *hirsutum* there was a very rapid replacement of indigenous types by the upland or American types. Evidently, many indigenous desirable types were lost in this course of evolution (Santhanam, 1981).

2.2 Pest problems

Rainwater (1952) remarked that 'cotton' is a plant specially tailored for insects. As many as 1326 species of insect pests have been listed on this crop in the world (Hargreaves, 1948). Sohi (1964) gave a list of 160 insects and mites on cotton in India. Most of these insects belong to four orders, namely, Lepidoptera, Orthoptera, Coleoptera and Hemiptera.

The crop is under attack by one or more species from the time it is planted to harvest and all parts are vulnerable to their attack. The germinating seeds are attacked by termites, gryllids, thrips, cutworms etc. Later, the foliage is attacked by jassids, aphids, thrips whiteflies and several lepidopterous larvae. The reproductives are attacked by bollweevil, bollworms and sucking pests.
No cotton growing region escapes the insects. However, different pest complexes are associated with various regions. The spotted bollworms are found throughout the Far East and extends to Asia and Australia. Whiteflies are often serious in African and Asian countries and Sudan. The *Spodoptera littoralis* is serious in Middle East countries (Agarwal *et al.*, 1987).

2.2.1 Major insect pests:

**World:**

Only forty six insects were of importance on cotton occurring in 32 countries. Interestingly, only six insects, *viz.*, *Aphis gossypii*, jassid, thrips, *Pectinophora gossypiella*, *Earias* spp. and *Heliothis armigera* were found in most of the countries. Thus, these could be classified as pests of global economic importance and needed control measures regularly (Aston and Winfield, 1972).

**India:**

Many of the insects recorded on cotton in India, are of sporadic nature and are time and space bound. But, five of them, namely, jassid (*Amrasca biguttula biguttula*
(Ishida), spotted bollworms (*Earias vitella* F. and *E. insulana* Boisd.) American bollworm (*Heliothis armigera* Hubn.) and pink bollworm (*Pectinophora gossypiella* Saunders) are rather ubiquitous and occur year after year. Earlier, the leaf roller (*Sylepta derogata* Fabricius) was also a major pest and completely devastated the cotton in Uttar Pradesh (Agarwal et al., 1987). Recently Geddes and Iles (1991) in their compilation of crop pests in South Asia also reported similar pests as most dominating (including whitefly) in India.

**Madhya Pradesh:**

In Madhya Pradesh, the important pests damaging cotton crop are almost the same those of global economic importance and may be divided into following two groups: (a) **Sucking pests**: Major sucking pests include first three of global economic importance, namely, (1) Aphid, *Aphis gossypii* Glover (Aphididae; Hemiptera) (2) Jassid, *Amrasca biguttula biguttula* Ishida (Cicadellidae; Hemiptera) (3) Thrips, *Scirtothrips dorsalis* Hood and *Thrips tabaci* Lindemann (Thripidae: Thysanoptera) (4) Newly emerged as major pest, the whitefly, *Bemisia tabaci* Gennadius (Aleyrodidae; Hemiptera).
(b) **Bollworms**: These are considered to be the most dangerous pests of cotton and comprise, (1) American or green bollworm, *Helicoverpa armigera* Hubner (Noctuidae; Lepidoptera) (2) Spotted bollworms, *Earias vitella* Fabricius and *E. insulana* Boisduval (Noctuidae; Lepidoptera) (3) Pink bollworm, *Pectinophora gossypiella* Saunders (Gelechiidae; Lepidoptera) (Gupta et al., 1971; Geddes and Iles, 1991).

2.3 **Biology of American bollworm, Helicoverpa (Heliothis) armigera** Hubner

The genus *Heliothis* consists of about 80 species (Todd, 1978). Of which, only *H. armigera* (Hubner), *H. zea* (Boddie) and *H. virescens* (Fabricius) are major pests of crops in the world and *H. armigera* recorded from India is the only predominating species inflicting economic damage to most of the crops (Singh and Sidhu, 1988).

Based on the morphological differences, Hardwick (1935) proposed the generic name *Helicoverpa* for *Heliothis armigera, H. zea, H. assulta* and *H. punctigera*. Since, this nomenclature is not yet wide spread, species *armigera* is still placed under genus *Heliothis* by majority of the workers.
**Heliothis armigera** is widely distributed occurring throughout the Africa, the Middle East, Southern Europe, Asia, Australia, New Zealand and many eastern Pacific Islands. The host range is very wide covering 96 cultivated and 61 uncultivated plant species (Bhatnagar and Davies, 1978). Among these, most preferred crop plants are chickpea, cotton, pigeonpea, sorghum, maize, sunflower, safflower, groundnut, tobacco, tomato, brinjal, okra, cucurbits etc. Some weed plants like *Datura* spp., *Acanthospermum hispidum* Dc., *Gynandropsis gynandra* Briq. and *Heliotropium ellipticum* Ladebour play important role in carry over of this pest (Singh and Bains, 1986; Sachan, 1987).

Many workers attempted the biology of this pest on various hosts in India and abroad. The informations available are summarised as below:

2.3.1 Egg:

The eggs were hemispherical with flat base and prominently ribbed. The colour of fresh eggs was yellowish which became darker prior to hatching. The dimensions of the eggs were reported 0.43 to 0.63 mm (Ewing et al., 1947; Edwards and Heath, 1964; Singh and Singh, 1975;
Kashyap and Dhindsa, 1990). Whereas, Dubey et al. (1978) Nayar et al. (1980) and Yadav et al. (1980) reported that eggs of H. armigera were spherical in shape.

Incubation period was longer in cold weather and shorter in hot weather, it was recorded 8 days in South Africa (Pearson and Darling, 1958) and 2 to 5 days in Western Tanganyika (Reed, 1965). Similarly in India, it was reported 2.7 to 8 days (Shrivastava and Saxena, 1958; Singh and Singh, 1975; Tripathi, 1985; Singh and Sidhu, 1988; Kashyap and Dhindsa, 1990).

2.3.2 Larva

There were normally six instars in H. armigera (Shrivastava and Saxena, 1958; Ismail and Swailem, 1976; Sachan, 1987; Goyal and Rathore, 1988). But, exceptionally, during cold season, seven instars were regularly found in Southern Rhodesia (Pearson and Darling, 1958). While Dubey et al., (1978) and Kashyap and Dhindsa (1990) reported only five instars in India. Whereas, Twine (1978) observed varied number of instars in different generations, being five or six in first two generations and six or seven instars in fifth generation on maize crop in Queensland.
There were great variations in colour within and between different larval instars. Neonate larvae were measured 1.49 ± 0.08 mm in length. It was translucent and yellowish white in colour with brown head. Full grown caterpillars were measured 34 to 42 mm in length. Short white hairs were scattered all over the body. Head was red brown and setae were dark. There was one pair of spiracles on pleural side of prothorax and first eight abdominal segments. Each thoracic segment carried a pair of true legs. Abdomen was ten segmented carrying prolegs with flat apices on third to sixth and tenth abdominal segments. Crochets were arranged in a biordinal symmetry on the prolegs. There were five broken longitudinal stripes on dorsal surface in varied colour and one broken stripe on each lateral side (Lefroy, 1906; Edwards and Heath, 1964; Singh and Singh, 1975; Dubey et al., 1978; Singh and Sidhu, 1988; Kashyap and Dhindsa, 1990). However, Singh and Singh (1975) did not observe dorsal longitudinal lines as broken.

Dubey et al. (1978) measured all five instars in length to be 1.5 to 2.2, 3.0 to 6.5, 12 to 16, 20 to 26 and 28 to 36 mm respectively. Whereas, Kashyap and Dhindsa (1990) measured them of 1.24 X 0.47, 3.44 X 0.74, 9.40 X 2.83, 22.16 X 3.30 and 32.78 X 5.08 mm in length X width.
Several authors have attempted to study the applicability of Dyar's Law (Dyar, 1890) in different insects belonging to different orders. Gaines and Cambell (1935) and Wigglesworth (1972) also tried to apply this law in *Heliothis* sp., but, increase in head width of different larval instars did not show geometric progression and difference between observed and calculated width of head capsules did not range in-between 0.00 to 0.14 mm.

The larval duration varied from 21 to 40 days in California, 18 to 51 days in Ohio (Wilcox *et al.*, 1956). According to Pearson and Darling (1958) the length of larval life ranged 15 to 32 days in South Africa and 18 to 35 days in Nyasaland. Whereas, Coaker (1959) recorded 21.8 to 36.6 days larval period in Uganda.

In India, Shrivastava and Saxena (1958) reported larval stage of 21 to 28 days on chickpea. Singh and Singh (1975) observed 8 to 12 days on tomato, while, larval stage lasted for 16 to 19 days on gram (Dubey *et al.*, 1978), 17 to 20 days on eight species of host plants (Dhandapani and Balasubramanian, 1980 b), 10.1 to 10.9 days on gram and 15.75 to 16.36 days on cotton
(Singh and Sidhu, 1988), 19.2 days (36.6, 80, 107 and 168 hours in 1st to 5th instars) on pigeonpea (Kashyap and Dhindsa, 1990) and 12.6 to 19.4 days (3.07 - 4.50, 2.58 - 3.73, 2.20 - 3.17, 2.22 - 4.50 and 2.57 - 3.50 days in five instars respectively) on cotton (Singh et al., 1992). Each of the workers reported longer larval duration in cold weather and shorter in hot weather.

First and second instar larvae were photonegative and used to feed beneath the leaves by scraping the epidermis. In later instars, feeding was done by intruding the head inside the buds, bolls, fruits and pods of different crops (Singh and Singh, 1975; Dubey et al., 1978; Goyal and Rathore, 1988; Kashyap and Dhindsa, 1990). Approximately, 80 per cent of the larval food was consumed during last larval instar. (Dhandapani and Balasubramanian, 1980 a). Seshu Reddy (1973) and Sachan (1987) observed cannibalistic behaviour in all the larval instars with maximum tendency in later instars.

Prepupal period was reported 1 to 2 days (Singh and Singh, 1975; Dubey et al., 1978) and 1 to 6.9 days (Chaudhary and Sharma, 1981; Singh and Sidhu, 1988).
2.3.3 Pupa:

It was obect measuring 14 to 22mm in length, 4 to 5 mm in width and 130 to 306 mg in weight (Singh and Singh, 1975). Narayanan et al. (1977) observed the genital pore on 8th and 9th abdominal segments in female and male pupae respectively. Pupal period was passed in an earthen cell prepared in soil at a depth of 3 to 6cm (Wilcox et al., 1956; Coaker, 1959; Singh and Singh, 1975; Sachan, 1987; Singh and Sidhu, 1988).

The pupal period of *H. armigera* varied 14 to 57 days in Rhodesia, Tanganyika, Uganda and Nyasaland (Pearson and Darling, 1958). In India, Singh and Singh (1975) and Dubey et al. (1978) reported the pupal period of 5 to 8 and 10 to 18 days respectively. Pupae underwent facultative diapause for 65.6 to 140 days during winter (Sachan, 1987; Singh and Sidhu, 1988; Kashyap and Dhindsa, 1990; Singh et al., 1992). According to Pearson and Darling (1958) all pupae did not undergo in diapause even in coldest months.

2.3.4 Life cycle period:

Total life cycle period from egg to adult emergence was recorded 15.6 to 23.6 days on tomato (Singh and Singh, 1975), 28 to 40 days on gram (Dubey et al., 1978) and 20 to 176 days on various crops including cotton (Singh and Sidhu, 1988).

2.3.5 Moth:

The colour, size and wings of male and female moths have been described and the sexes were identified by the
presence of tuft of hairs on the tip of abdomen in females (Ewing et al., 1947; Singh and Singh, 1975; Dubey et al., 1978; Kashyap and Dhindsa, 1990). Moths used to emerge in the night during 18.00 to 22.00 hours. Males outnumbered females and male : female ratio was observed 60 : 40 by Singh and Singh (1975) and Dubey et al. (1978). Premating period lasted in one to two days (Singh and Singh 1975; Kashyap and Dhindsa, 1990). Moths mated once only and took a period of 10 minutes 45 seconds (Singh and Singh, 1975). Longevity of males was reported 2 to 3.13 days (Singh and Singh, 1975; Dubey et al., 1978).

Pre-oviposition, oviposition and post-oviposition periods ranged 1 to 4, 2 to 8 and 0.4 to 2 days respectively (Patel et al., 1968; Singh and Singh, 1975; Ismail and Swailem, 1976). Longevity of females was observed 18 days (Szukowski, 1954), 30 days (Reed, 1965), 5 to 11 days (Patel et al., 1968), 2.88 to 6.63 days (Singh and Singh, 1975) and 4 to < 20 days (Singh and Sidhu, 1988).

2.3.6 Oviposition:

Female moth laid eggs singly in the late evening with maximum during 21.00 to 23.00 hour on leaves, buds, blooms, flowers, bolls, fruits and pods of different crops (Singh and Singh, 1975; Goyal and Rathore, 1988).
A female laid 198 to 3000 eggs (Ewing et al., 1947; Reed, 1965; Margal, 1990). According to Patel et al. (1968), fecundity ranged 510 to 1676 eggs. However, only 40 to 53 eggs per female were recorded in laboratory conditions (March to May) on tomato in Punjab (Singh and Singh, 1975). The number of eggs per female varied 22 to 284 on gram in Chhatisgarh (Dubey et al., 1978), 337 to 1346 on different hosts (Dhandapani and Balasubramanian, 1980 b) and from 258 to 466 on cotton and 414 to 505 on gram (Goyal and Rathore, 1988).

2.3.7 Generations:

Singh and Singh (1975) and Ismail and Swailem (1976) reported that *H. armigera* completed only four generations in a year. Whereas, five (Tripathi, 1985), seven (Seshu Reddy, 1973; Singh and Bains, 1986) and eight (Bhatnagar, 1980) generations were observed in varied hosts and climatic conditions. On the basis of male moth catches in pheromone traps Sinha and Jain (1992) reported 4-5 generations of this pest in a year.

2.4 Succession of major insect pests:

Katiyar (1977) reported that the infestation of
spotted bollworm started earlier than that of pink bollworm in cotton. The former attains its peak by middle of September while later appears by middle of August and the peak infestation is reached by the end of October.

Aphid, jassid and thrips may occur either alone or simultaneously and if occur together competition exists between them. In case aphid infestation is severe, jassid and thrips incidence is decreased (Murugesan, 1985; Kulkarni and Raodeo, 1986).

Agarwal et al. (1987) collected the data on occurrence of pests which indicated that jassids are first to attack the cotton crop which starts sometimes from the middle of June to end of September. Later, the spotted bollworms are serious during August to October and the pink bollworm is found from August to November under north Indian conditions.

Whitefly exhibited negative correlation with co-sucking pests, namely, aphid and jassid (Venugopal Rao and Reddy, 1987).

Venugopal Rao et al. (1990 a) discussed that if aphid population is suppressed effectively, it may
contribute indirectly for build up of whitefly, a competitive pest of the same niche. Vice versa increase in aphid infestation may result in the reduction of whitefly population.

2.5 Population dynamics of major insect pests

2.5.1 Aphid:

Humid weather with dizzling rain is highly favourable for aphid multiplication, while heavy showers completely wash out the aphids (Murugesan, 1985).

On arboreum cotton varieties (G 27, LD 133 and LD 230), maximum aphid activity period in Punjab ranged from second week of July to mid September. The population varied from 13-496 per 30 leaves (Dhawan et al., 1987a). Whereas, Kandoria et al. (1989) observed it most active from September to October in Punjab.

2.5.2 Jassid:

Environmental conditions played an important role in the population build up of the jassid. Atwal et al. (1969) reported that upto 70 % RH, the population was positively correlated with the relative humidity, beyond
this, it declined. The mean maximum and minimum temperature of 32 - 36 °C and 27 - 30 °C, respectively, relative humidity below 75 % and dry season favoured the multiplication of the jassid. But, rainfall above 4.4 mm reduced the population of jassid (Sekhon and Singh, 1985). High temperature and bright day (long sunshine hours) were detrimental to leaf hoppers (Murugesan, 1985). Sidhu and Dhawan (1986) also reported that continuous and heavy rains caused greater mortality of jassids, whereas early and light rains helped the multiplication of the pest.

The jassid was active on hirsutum cotton from July to August in Punjab and from July to September in Southern states. The activity period of jassid on arboreum cotton varieties (G 27, LD 133 and LD 230) ranged from mid June to mid August. The population counts per 30 leaves varied from 4 to 33 in different varieties (Dhawan et al., 1987a). The pest, in Punjab was practically active throughout the year, and during winter, only adults were found on tomato, potato and brinjal. In spring, it migrated to okra and then to cotton (Simwat, 1990).

The two peaks of jassid population in the month of August and again in the month of September at Delhi were observed by Kumar and Agarwal (1990).
2.5.3 Thrips:

Thrips appear soon after the germination if the weather is humid and disappear with the onset of heavy and continuous rains (Murugesan, 1985). Whereas, Al-Faisal and Kandori (1986) observed the high incidence of thrips during second half of August on American cotton. Young stage of plants, temperature above 35 °C and high relative humidity helped in the rapid multiplication of the pest.

2.5.4 Whitefly:

Outbreaks of whitefly in India were reported from Punjab (1930 and 1943), Andhra Pradesh (1984 and 1987), Tamil Nadu, Karnataka, Maharashtra (1985-87) and Gujarat (1986-87) (Reddy and Venugopal Rao, 1989).

The population build up of whitefly was positively correlated with temperature and rainfall, but negatively correlated with the relative humidity. Continuous rainfall and strong winds reduced the population of whitefly (Murugesan, 1985; Singh and Butter, 1985). Gerling et al. (1986) observed that preimaginal survival of B. tabaci varied inversely with relative humidity. It might be 2 - 80 % in the range of 31-90 % RH.
The pest was active on hirsutum cotton during July to August. On arboreum cotton, the insect was active from 2nd week of July to end of September. The population of adults varied from 9-37 per three leaves in different observations on various varieties in Punjab (Dhawan et al., 1987a).

Venugopal Rao and Reddy (1987) reported that the whitefly population build up was rapid during October-November when the maximum temperature ranged between 30.5 to 32.8 °C and minimum temperature 19.7 to 22.7 °C, the rainfall below 18 mm and RH between 75.8 to 82.1 %.

Natarajan (1988) reported that prolonged drought coupled with high temperature and the discontinue use of insecticides appeared to favour the outbreak of whitefly (Bemisia tabaci Gennadius). Intensive cropping, adoption of closer spacing, excessive application of nitrogen, elimination of competitive insects and natural enemies provide favourable conditions for the whitefly to upsurge.

Jayaswal(1989) reported that temperature of 28 to 36 °C, 60 to 92 % RH and scanty rainfall during August to January were favourable for this pest in South India.
Byrne and Bellows (1991) observed that population of whitefly in cotton appeared to increase exponentially during the middle part of the growing season. This might be in part result from the adaptation of the population to cotton as a host and in part from the suppression of natural enemy activity by insecticidal application.

2.5.5 American bollworm:

Population build up of *H. armigera* larvae was correlated positively with rainfall and minimum temperature and negatively with relative humidity in Madhya Pradesh (Vaishampayan and Veda, 1980) and Haryana (Kaushik and Naresh, 1984).

Three peaks in each year, viz., August to September, November to December and March to April were recorded by Pawar *et al.* (1984) in Andhra Pradesh. Whereas, first half of September was crucial period in Vidarbha and population was again high in first half of January and February (Anonymous, 1984-85b and 1986). While, Singh and Bains (1986) recorded two peak periods of larval activity i.e. end of March and first week of November in Punjab.
2.5.6 **Spotted bollworm:**

It was found active throughout the crop season, particularly during October and November in Madhya Pradesh (Kaushik et al., 1969). Intermittent rains followed by cloudy weather under fair high humidity around 75 ± 10 per cent at the mean temperature of 28 ± 1 °C provided conducive conditions for population build up of bollworms at Delhi (Katiyar, 1976). Whereas, mean temperature of 26.9 °C with 70.6 % RH and 25.2 mm rainfall was found to be congenial for *Earias* spp. in Marathwada (Raodeo et al., 1983) and maximum $I_m$ value was recorded at 30 °C and 70 % RH in Punjab (Gill, 1988).

The period of maximum damage caused by spotted bollworm varied in different regions being September in Marathwada, October–December in Gujarat and November–February in South India (Butani, 1978). Whereas, Taneja and Jayaswal (1984) noticed the activity of spotted bollworm on cotton from mid July to end of September with maximum during second fortnight of August in Haryana.

2.5.7 **Pink bollworm:**

In Madhya Pradesh, this pest is not so serious
but found active upto some extent from October to January, the peak period being November-December (Kaushik et al., 1969). In India, maximum damage due to pink bollworm is done from August to November. Mild and humid climate is conducive for the rapid multiplication of this pest. Long spells of dry hot weather results in reduced incidence. Day temperature from 75 to 82 °F and relative humidity from 60 to 80 % at the time of emergence of long cycle moths lead to rapid multiplication of this pest (Agarwal et al., 1976).

Taneja and Jayaswal (1984) observed the activities of *P. gossypiella* on cotton from mid August to mid November in Haryana. It was not seen in shed squares. A high incidence of pest was observed during October. Whereas, Sangappa et al. (1985) reported that the adult activity occurred throughout the year being highest in January-February at Raichur (Karnataka).

2.6 **Losses due to major insect pests**

2.6.1 **Due to sucking pests**:

Losses in seed cotton yield due to jassid (*Amrasca biguttula biguttula* Ishida) were estimated to the extent
of 25.43% (Bhat et al., 1984) and 50% (Agarwal et al., 1987) in Delhi, 11% (Sidhu and Dhawan, 1986) and 1.10 q/ha (Dhawan et al., 1988) in Punjab and 15.9% in Haryana (Singh and Lakra, 1990b).

Losses in seed cotton yield due to thrips were reported 262 kg/ha in Punjab (Sohi, 1964), whereas yield losses due to whitefly have been reported to the extent of 10-45% in Andhra Pradesh (Reddy et al., 1985) 25-40% in Maharashtra coastal area (Anonymous, 1986) and 1-31% in Punjab (Sukhija et al., 1987).

Total losses in seed cotton yield due to all sucking pests were estimated to the extent of 57.9% in Gujarat (Anonymous, 1982), 4.6% in All India Coordinated Cotton Project trials (Anonymous, 1984-85b), 9.74 q/ha in Punjab (Sukhija et al., 1987) and 4.6% in Maharashtra (Satpute et al., 1988).

2.6.2 Due to bollworms:

Losses in seed cotton yield due to bollworms were estimated to the tune of 33.17% in Madhya Pradesh (Kaushik et al., 1969), 78% in Gujarat (Murugesan, 1981),
29 to 34 % at Delhi (Bhat et al., 1984; Agarwal et al., 1987), 51.3 % in All India Coordinated Cotton Project trials (Anonymous, 1984-85b), 7.42 q/ha in Punjab (Dhawan et al., 1988) and 36.2 % in Haryana (Singh and Lakra, 1990 b).

2.6.3 Cumulative losses:

Cumulative losses in seed cotton yield due to sucking pests and bollworms were estimated to the extent of 77.4 % in Gujarat (Anonymous, 1982), 27.2 to 52.2 % in Haryana (Gupta, 1983; Singh and Lakra, 1990 b), 40.3 to 52.9 % in Maharashtra (Thakare and Radke, 1983; Satpute et al., 1988), 54.55 % in Delhi (Bhat et al., 1984 ), 52 % in All India Coordinated Cotton Project trials (Anonymous, 1984-85b ) and 10.05 to 10.57 q/ha in Punjab (Sukhija et al., 1987; Dhawan et al., 1988).

While, Dhawan et al. (1986) reported 94.6 and 66.5 % increase in seed cotton yield of G. hirsutum and G. arboreum due to insect pests control with the net profit of Rs 2645 and 1933 per ha respectively.
2.6.4 **Losses in phenology and quality:**

In addition to losses in seed cotton yield, phenology of plants and quality of cotton fibres were also adversely affected due to insect pests' damage.

**Phenology:**

Murugesan *et al.* (1979) observed significant differences in plant growth by controlling insect pests with the application of cypermethrin.

Regupathy (1981) and Vendramin and Nakao (1981) reported that the growth and dry matter production were reduced to the extent of 38 to 44% by jassid, thrips and aphid. Agarwal *et al.* (1983) observed noticeable increase in plant height by controlling jassid. But, Gupta and Agarwal (1985) did not find any difference in the heights of treated (for bollworms control) and untreated plants.

Kumar *et al.* (1985) observed more height of plants treated with synthetic pyrethroids than those treated with monocrotophos and untreated (control). Kulkarni and Raodeo (1986) reported considerable reduction in
plant height, drymatter, leaf area and monopodial branches of glabrous hybrid H 4 due to the attack of sucking pests: jassid, aphid and thrips.

Singh and Lakra (1990 a) observed that application of monocrotophos ( 450 and 300 g a.i/ha ) and endosulfan ( 800 and 600 g a.i./ha ) led to more plant height and leaf surface area than the untreated control. Plots treated with these insecticides had lesser reduction in leaf surface area till last picking.

Quality :

Salesh and Eldin (1982) when determined the effect of different insecticides on ten different parameters of fibre quality, found significant differences only for micronaire value and maturity ratio while only marginal in fibre length and bundle strength. Madan et al. (1987) observed significant improvement only in span length (2.5 % ) with the treatment of decamethrin.

Dhawan et al. (1987 b) reported that the fibre fineness and bundle strength were not affected by pink bollworm damage in *Gossypium hirsutum* while in *G. arboreum*, fibre fineness was reduced.
2.7. Screening of varieties for resistance to major insect pests

The development of varieties of cotton resistant to different key pests, without sacrificing quality and yield, offers the most hope of success in pest control. This type of control is compatible with other methods of pest control and is therefore very much favoured to all programmes of integrated pest management. Multifactorial resistance is favoured over monogenic resistance because of low probability of it's breaking down by the new biotypes of insects. A wide range of cotton cultivars are found resistant to insect attack in the screening tests conducted by many workers.

2.7.1 Resistance against sucking pests:

(i) Aphid: In a laboratory trial, Bottger et al. (1964) found gossypol to be highly toxic to cotton aphid. Whereas, studies of Gawaad and Soliman (1972) showed that hairiness and resistance to aphids were not correlated. Dariev et al. (1979) found that susceptibility to aphids is associated with smoothness of cotton leaves.

Khan and Agarwal (1990) screened 11 varieties of cotton against aphid (Aphis gossypii). Sujay and M-495
were least preferred. The varieties with glabrous or dense pubescent leaf surface were least preferred as compared to moderately hairy varieties.

(ii) Jassid: Singh et al. (1972) have screened some varieties of cotton and reported less hairy varieties as resistant to jassid, *Amrasca devastans* Dist.

Agarwal et al. (1978) screened 48 varieties of cotton consisting 26 *G. hirsutum*, 7 *G. herbaceum* and 15 *G. arboreum* and found B 147 and Khandwa 1, 2, 3 (*G. hirsutum*) as highly resistant to jassid, *A. devastans*. Whereas, 39 varieties were moderately resistant and 5 were moderately susceptible types. They further reported that resistance in cotton to *A. devastans* was not a simple phenomenon but was due to a combination of several physical and biochemical factors in the plants and they impart resistance more or less in a complementary manner. Physical characters interfere in feeding and oviposition while biochemical characters affect feeding and nutritional requirements.

Dense epidermal hairs, hair length and leathery lamina were indentified as morphological characters to induce resistance to cotton jassid (Balasubramanian et al., 1978; Ramaseshaiah et al., 1980; Ambekar and Kalbhor, 1981;
Santhanam, 1981; Singh, 1987). Agarwal et al. (1983) have found that jassid resistant varieties like Bikaneri nerma and H 14 have minimum insecticidal requirement as compared to others.

According to Khan and Agarwal (1984) cotton varieties having the effective hair length on the midveins of lower surface of leaves (longer than ovipositor of female) were not preferred for oviposition by the jassid. On the basis of antibiotic study Bhat et al. (1985) reported that G. arboreum (G 27) was not found as much resistant as NHH-1 strain of G. hirsutum.

Sidhu and Dhawan (1986) while estimating the losses caused by jassid, found F 414 highly tolerant as compared to J 205.

Kumar and Agarwal (1990) found variety H-14 moderately resistant against cotton jassid over PS-10. While, Purohit and Deshpande (1991) observed significantly higher population of jassid on H 4 as compared to Purnima (G. hirsutum) and Eknath (G. arboreum).

(iii) Whitefly: In the screening of germplasm collection at Regional Agricultural Research Station, Lam (Guntur),
few lines like S-8/3, JK 276-1, JK 345 and FBRN 2-6 were found least susceptible to whitefly. LK 861, Amravathi and LPS 141 varieties exhibited appreciable degree of tolerance to whitefly as compared to popularly grown varieties like MCU 5 and LRA 5166 (Anonymous, 1980-84). Whereas, Butler et al. (1984) reported varieties, AET 5, Deltapine 61 and Deltapine 62 as resistant to whitefly.

The population of whitefly was positively correlated with the number of leaves per plant, thickness of leaf lamina and hair density. Whereas, phenol content and pH of cell sap of leaves were correlated negatively (Chakravarthy et al., 1985). Murugesan (1985) also reported that presence of dense leaf cover with hairs favours the development of whitefly population on cotton.

Variety, Supriya was found tolerant to whitefly (Anonymous, 1986). Butler and Vir (1989) indentified sparsely hairy cotton genotype USA-22 as resistant to whitefly, while, Kanchna, Supriya and LRA 861 were identified as tolerant to whitefly. They further stated that hairy varieties with thin leaf lamina are known to impart sufficient resistance to cotton whitefly. Whereas, Jayaswal (1989) in Andhra Pradesh indentified LK 861, LPS 141, JK 276-1, JK 345 and FBRN 6 as tolerant to whitefly.
2.7.2 Resistance against bollworms:

(i) **American bollworm**: Singh et al. (1988) have reported only 20% *Heliothis* neonate survival on *arboreum* variety G 27 and *hirsutum* variety F 286 against 100% survival on Jhurar and F 505 (*hirsutum*).

Bikaneri nerma and it's genotypes usually limit the damage caused by *Heliothis*. Terpinoids like high gossypol (heliocides) impart resistance to cotton against *H. armigera* (Singh, 1990).

(ii) **Spotted bollworm**: Agarwal and Katiyar (1974) observed that the moths of spotted bollworm deposited more eggs on varieties having dense population of hairs on leaves. Amongst the varieties tested B 1007 and Badnawar 1 being highly hairy harboured highest number of eggs. Whereas, PS 1 and PS 10 smooth in nature harboured only a few.

The cultivars like L 1245, JK 119-2554, BGS 10-25, FBRN-2-6 and HAO 66-107-1/1 were observed tolerant to spotted bollworm (Anonymous, 1980-84). Duhoon and Singh (1980) made four groups of different genotypes of *G. arboreum*
against spotted bollworm; the first group included Cerruum, Lohit, G 27 and LD 135 as resistant. Medium resistant group consisted Y-1 and Daulat; susceptible group included 877, CJ 73, virnar and 1946 and highly susceptible ones were AKI 4, 875, 965 and 1042.

Singh (1985) indentified varieties, Sanguenium from G. arboreum as least susceptible and Line 199-77-25-4 from G. barbadense as moderately susceptible. While, BJR-741, 264-1, glandless 38-6 A and Acacia 4-42 were screened as susceptible, Fregó-bract and Mc Nai. as moderately susceptible and XC-15-USA as least susceptible from G. hirsutum against spotted bollworm, Earias vit. lla (Fab.). Singh and Agarwal (1987a) have found that XC-15-USA, Sanguenium and short staple varieties proved least susceptible under field as well as laboratory conditions and may be utilised for developing resistant varieties against E. vitella.

(iii) Pink bollworm: Agarwal et al. (1976) reviewed the mechanism of resistance in different Gossypium to pink bollworm. Absence of bracts, nectarless, glabrous leaves, cell proliferation and high gossypol content impart resistance to this ubiquitous pest of cotton. Earliness is found one of the important characters for escaping the pink bollworm attack.
Taneja and Jayaswal (1984) screened 9 varieties of cotton against *Pectinophora gossypiella* incidence. The lowest incidence was recorded on G 27 and Bikaneri nerma.

Singh and Agarwal (1987b) also studied the reaction of cotton varieties to pink bollworm infestation at final picking. Variety SS-265 was found to be highly resistant, while, varieties PS-10 and M-495 were found to be highly susceptible.

2.7.3 **Multiple resistance** :

Hairiness of lamina is considered to be one of the factors conferring resistance against jassid. However, varieties possessing hairy leaves are preferred for infestation by aphid, thrips, whitefly and early bollworms. Oviposition by bollworm moths is also observed to be higher on the hairy tender shoots and leaves (Santhanam, 1981).

Bhat *et al.* (1984) identified moderately hairy and early maturing variety Bikaneri nerma quite resistant to jassid and also least susceptible to bollworms.

Many varieties of cotton were screened against jassid population and bollworms' damage at College of
Agriculture, Khandwa. Sharda, NH 290 and Khandwa 2 recorded lowest damage caused by bollworms. Among hirsutum strains, none of the entries out crossed Khandwa 2 and G. cotton-10 in jassid tolerance. However, considering yield and mean jassid grade NH 290 and 79 BH 5-3 were found promising (Anonymous, 1984-85a).

Chakravarthy and Sidhu (1986) reported arboreum varieties, G 27, LD 133 and LD 230 more resistant than F 414 to cotton jassid and aphid. While, hairy hybrid NHH 1 was found more resistant to sucking pests (jassid, aphid and thrips) as compared to glabrous hybrid H 4 (Kulkarni and Raodeo, 1986).

A new genotype "Abadhita" is found tolerant to cotton bollworms in Karnataka state (Bulter, 1990). He has also informed that genotypes Reba B-50, DHY-287, RS-73, Khandwa-2, LH-137, H-854 have been identified as resistant to cotton jassid and are being used in the hybridisation programme for developing resistant varieties.

The incidence of jassid, whitefly and bollworms was significantly lower in F 575 than the standard F 286 and other eight varieties (Dhawan et al., 1990). Central
Institute of Cotton Research, Nagpur has developed CICR HH 1 cotton hybrid which has resistance to multiple pests (Anonymous, 1991-92).

2.8 Efficacy of insecticides against major insect pests

Insecticides are generally the first line of defence in the control of insect pests. They have been employed because they are highly effective, their effect is immediate and they can rapidly bring large insect populations under control. They can be employed as needed. The use of insecticides seems to be necessary for crop pests management. A large number of insecticides have been tested against cotton pests. The work done in last three decades influence the present management system of cotton pests.

2.8.1 Against major sucking pests:

Kumar et al. (1966) studied the effectiveness of 12 insecticides against Empoasca devastans and found dimethoate, parathion and carbaryl more effective. Whereas, Hassanein et al. (1970) found systemic insecticides methyl demeton, dimethoate and vanidothin (Kilval) as best compounds against Empoasca in cotton.
Gera and Chopra (1975) found systemic insecticides methyl demeton (0.01 %), thiometon (0.1 %) and dimethoate (0.03 %) superior over non-systemic insecticides against cotton jassid and persisted for 28, 26 and 26 days respectively.

Harcharan Singh and Vijay (1975) observed LV and ULV applications of dimethoate highly effective against thrips, I. tabaci on cotton. Whereas, Sidhu and Dhawan (1976) recommended foliar application of dimethoate @ 0.03 kg a.i./ha at one jassid nymph per leaf as threshold level and found effective as compared to standard treatments to control jassid.

Natarajan et al. (1977) reported that fenitrothion not only registered good control over the sucking pests but also increased the yield by 137 % followed by formothion, phosphamidon, dimethoate and monocrotophos.

Monocrotophos and carbaryl sprayings caused cotton almost free (0.1 - 0.4/leaf) of aphid, while plots sprayed with synthetic pyrethroid had aphid population to the extent of 12.5/leaf at Coimbatore (Murugesan et al., 1979).
Oxydemeton methyl, dimethoate and phosphamidon (each 0.3 kg a.i./ha), monocrotophos, quinalphos and endosulfan (each at 0.5 kg a.i./ha) were effective for the control of thrips. Carbaryl and malathion were not so effective (Sidhu and Dhawan, 1979). Further, Sidhu et al. (1979) found that phenthoate, quinalphos, phosalone and monocrotophos applied @ 0.3 kg a.i./ha were as effective as dimethoate at the same rate against jassid and other sucking pests.

Experiments conducted at Regional Agricultural Research Station, Lam (Guntur) for several seasons indicated that early occurring sucking pests like jassid, aphid and thrips may be controlled effectively with two sprays spaced at fortnightly intervals commencing from 15 days after sowing with either dimethoate (0.04 %) or methyl demeton (0.05 %) or phosphamidon (0.05 %). Alternatively, one application of granular insecticides like carbofuran or phorate @ 1 to 1.25 kg a.i./ha after 10-15 days of sowing by pocketing method was also equally effective for the control of early sucking pests (Anonymous, 1980-84).

Bhamburkar (1980) achieved the maximum reduction in sucking pests population and highest yield of seed
cotton, when the crop was treated with phosphamidon 0.34 kg a.i./ha (twice) followed by dimethoate, acephate and methamidophos 0.6, 0.5 and 0.8 kg a.i./ha respectively.

Dahia and Singh (1982) found vamidothion 0.06 % as best insecticide against jassid. Similarly, monocrotophos was more effective against whitefly and phenthoate, quinalphos, phosalone and monocrotophos were found as effective as dimethoate against thrips.

Agarwal et al. (1983) recorded that susceptible varieties to jassid need more number of insecticidal sprays to get satisfactory yield and as such 3 sprayings (monocrotophos/carbaryl) were needed to control jassid on such varieties.

In Karnataka, jassid and whitefly were controlled by the foliar spray of oxydemeton methyl, phosphamidon (0.266, 0.375 kg a.i./ha) or dimethoate (0.383 kg a.i./ha) (Anonymous, 1985).

Patel et al. (1985b) found that jassid was controlled to 93.3 % by foliar spray of vamidothion (0.03 %) followed by phosphamidon (0.03 %), whereas,
thrips were controlled to 97.7% with vamidothion followed by dimethoate (0.03%). However, aphid was controlled to 99.8% with phosphamidon 0.03%.

Reddy et al. (1985) found that the incidence and secondary outbreak of whitefly caused by synthetic pyrethroids may be controlled with spraying of triazophos or monocrotophos or acephate @ 0.1% at weekly intervals. In another studies, monocrotophos, ekalux, acephate and triazophos were also found effective to control whitefly. Nicotine sulphate, neem kernel extract and fish oil resin soap were also effective (Anonymous, 1986).

Chakravarthy and Balasubramanian (1986) recommended vamidothion @ 0.400 kg a.i./ha or oxymefetan methyl @ 0.183 kg a.i./ha or dimethoate @ 0.225 kg a.i./ha or monocrotophos @ 0.150 kg a.i./ha in 3 sprays at 15, 30 and 45 days after sowing against cotton jassid.

Thimmaiah et al. (1987) found considerable reduction of leaf hoppers and thrips attack in two soil applications of phorate followed by four foliar applications of endosulfan from 105 to 150 days old crop at Dharwad (Karnataka).
Babu and Gupta (1988) observed that two sprays of dimethoate (0.04 %) at 15 days interval were equally effective as soil insecticides in controlling jassid upto 39 days below ETL.

Dhawan and Simwat (1988) recommended the foliar spray of dimethoate or oxydemeton-methyl or phosphamidon @ 0.188 kg a.i./ha for the control of jassid and whitefly in Punjab. Daware (1989) applied three sprays of dimethoate at 15 days interval, started from 15 days crop stage and found significantly higher yield of seed cotton.

Reddy and Venugopal Rao (1989) advised to resort on spraying of phosalone (2.5 l/ha) combined with neem oil (0.3 %) or fish oil resin soap (1 %) at 750-1000 l spray solution/ha to control whitefly. They also advised to use triazophos (0.05-0.1 %) when whitefly is predominant and acephate (0.07-0.1 %), if aphid and bollworms are predominant. They also stated that farmers should resort on high volume sprayings only and that too on a community basis in a particular area to manage the whitefly outbreak.

Singh and Lakra (1989) generated the information that the lower dose of dimethoate (250 ml/ha), oxydemeton
methyl (250 ml/ha) and phosphamidon (62.5 ml/ha) proved almost as effective as their respective higher dosages (upto 4 times) till 15 days of application.

According to Verma et al. (1989), quinalphos, amitraz, triazophos @ 1 kg a.i./ha and neem oil (0.5 %) + teepol (5 : 1) (3 litres + 0.6 litres/ha) reduced the population of whitefly by 96-99 %. Whereas, acephate @ 1.0 kg a.i./ha gave 78 % control of whitefly in Madhya Pradesh.

Venugopal Rao et al. (1990a) found amitraz, triazophos, profenphos (0.01 %) and fenpropethrin (0.02 %) most effective against cotton whitefly. In another trial Venugopal Rao et al. (1990b) reported triazophos, fenpropethrin, mineral oil and deltapthos significantly effective on all stages of cotton whitefly. Whereas, aphid infestation was totally absent in acephate, amitraz, monocrotophos, neem oil and methyl demeton treatments, while, highest aphid incidence of 124 per leaf was recorded in cypermethrin treatment.

Systemic insecticides, viz., monocrotophos and dimethoate were found more effective against jassid and
whitefly population as compared to contact poisons, viz., quinalphos and fenvalerate at all the spray intervals (10, 15, 20 and on need based). Systemics were found to be effective even at 20 days spray interval (El-Shahawy et al., 1991). Dimethoate 0.04 % also reduced the jassid population below ETL (one nymph/leaf) upto 17 days of its application (Singh, 1991).

2.8.2 Against bollworms:

Subramanian (1971) screened conventional insecticides like carbaryl, endosulfan and monocrotophos against cotton pests and found very effective when applied 4-5 times from the square stage at fortnightly interval.

Sidhu and Dhawan (1977) suggested a total of six sprays of DDT, endosulfan and fenitrothion for the control of pink bollworm on cotton and advised initiation of sprays at 2 weeks after the onset of flowering, repeated at 2 week intervals.

Murugesan and Parameswaran (1979) tested fenvalerate (0.04 %) and monocrotophos (0.05 %) against bollworms and found minimum incidence (5.6 %) in green bolls and (3.6 %)
in open bolls on locule basis in fenvalerate treated plots and significantly higher yield (1466 kg/ha) was obtained.

Synthetic pyrethroids like permethrin (100g), cypermethrin (60g), deltamethrin (15g) and fenvalerate (75g) were highly effective in controlling bollworms as compared to conventional insecticides and natural pyrethroids and contributed for higher yields (Reddy et al., 1980; Rosaiah and Reddy, 1982).

Sorathia and Chari (1981) have reported that the fenvalerate gave effective control of bollworms than phosalone, quinalphos, phenthoate, phoxin and entrinphos and the C : B ratio was also high (1 : 3) with fenvalerate as compared to 1 : 2 and 1 : 1.4 with phosalone and quinalphos respectively.

The different bollworms like spotted, green and pink bollworms can be controlled with spraying of carbaryl (0.15 %) or monocrotophos (0.05 %) or quinalphos (0.075 %) or acephate (0.1 %) or methomyl (0.05 %) at 10 day intervals (Anonymous, 1982).

Cypermethrin 60 to 100 g a.i./ha was observed to be very effective against cotton bollworms as compared
to conventional insecticides and other synthetic pyrethroids and also gave higher yield of seed cotton (Awate et al., 1982; Basu et al., 1983; Chari et al., 1983 b; Murugesan et al., 1983; Shirshikar et al., 1986).

Chari et al. (1983 a) indicated that fenvalerate @ 100 g a.i./ha was most effective against bollworms on H-4 and increased the yield of seed cotton. They also suggested to spray fenvalerate alternately with conventional insecticides. Vaissyre (1983) found that the combination of cypermethrin (30 g a.i./ha) with triazophos (150 g a.i./ha) was very effective against pink bollworm, whereas, with profenphos(300 g a.i./ha), it was very effective against American bollworm.

Synthetic pyrethroids were more effective than the standard carbaryl. Among synthetic pyrethroids, flucythrinate @ 50 g a.i./ha gave the most effective control of bollworms. Highest yield of seed cotton (LD 133) was recorded in flucythrinate @ 25 g a.i./ha in combination with monocrotophos @ 200 g a.i./ha, later controlled the resurgence of sucking pests (Duhoon and Banerjee, 1984).

Gupta et al. (1984) have found that the two dosages of synthetic pyrethroids, viz., flucythrinate (30, 50 g a. i./ha), fenvalerate (40, 75 g a. i./ha) applied at
15 days intervals were most effective against *Earias vitella*, *E. insulana* and *Pectinophora gossypiella*. But, there was no significant difference between two dosages in any treatment. Insecticides in EC formulations were found better than ultra low volume formulations in reducing bollworm damage. Phosalone sprayed crop showed a peculiar red colour (Anonymous, 1984-85a).

Gupta and Agarwal (1985) have found 5 rounds of spraying with fenvalerate (0.01 %) commenced with setting of flowers in about 50 % plants, very effective in reducing the incidence of bollworms and increasing seed cotton yield. In another experiment, Gupta and Katiyar (1985) found deltamethrin (10 g a.i./ha) and fenvalerate (40 or 75 g a.i./ha) most effective with maximum C : B ratio of 1 : 3.4 and 1 : 3.1 respectively.

Patel et al. (1985a) have emphasised the need based schedule of synthetic pyrethroid for the control of bollworms and found that monocrotophos/cypermethrin schedule gave highest yield of seed cotton (2512 kg/ha) and remained at par with carbaryl/fenvalerate, monocrotophos/endosulfan/decamethrin and carbaryl/endosulfan/ fenvalerate schedules. The C : B ratio was maximum (1:9.9) in monocrotophos/cypermethrin and carbaryl/fenvalerate schedules.
Shekli et al. (1986) have found that four sprays of 0.01 % cypermethrin alternating with four or three sprays of 0.06 % monocrotophos reduced the incidence of bollworms (Earias vitella, Pectinophora gossypiella and Heliothis armigera) significantly and also produced higher yield of seed cotton (34.56 q/ha). It has been also observed by the authors that increase in number of insecticidal sprays increased whitefly (Bemisia tabaci) population.

Singh et al. (1987) found that the control of bollworms through 3–4 applications of monocrotophos from 2nd fortnight of August and whole month of September played pivotal role in realising good yield of seed cotton. They suggested that missing of spray either at the end of August or in September will reduce the yield of seed cotton, significantly. So if any farmer wants to miss a spray due to paucity of funds, he should miss it only in the beginning of August for harvesting good cotton crop.

Gupta and Katiyar (1988) found cyhalothrin (50g a.i./ha), flucythrinate (50 g a.i./ha) and fenvalerate (dust LVC and EC formulation @ 75 g a.i./ha each) effective in reducing incidence of bollworms and increasing
the yield of seed cotton. Amongst synthetic pyrethroids, whitefly population build up was minimum in fenpropethrin (100 g a.i./ha) and cyhalothrin (50 g a.i./ha) treated plots. However, maximum build up of whitefly population was observed in all the formulations of fenvalerate. But, there was no build up of whitefly population in triazophos treated plots rather this insecticide was effective in checking its population.

Patel and Bhalani (1988) observed four insecticidal spray schedules using 1-5 applications of monocrotophos (0.05 %), carbaryl (0.02 %), endosulfan (0.07 %) and dimethoate (0.03 %) very effective in controlling the pests of cotton, viz., A. devastans, Earias spp. and H. armigera and increasing seed cotton yield.

Singh et al. (1989) have reported that two applications (2nd and 4th) of synthetic pyrethroids with three applications (1st, 3rd and 5th) of conventional insecticides resulted in significantly low incidence of bollworms and higher seed cotton yield. Similarly, Bramhankar et al. (1990) have noted that all the synthetic pyrethroids alternated with conventional insecticides, specially with triazophos (0.08 %) were most effective in increasing the weight of bolls and thus giving an increased yield of seed cotton next to the lone use of pyrethroids.
Gupta et al. (1990) observed minimum incidence of bollworms and maximum yield of seed cotton with flucy-thrin rate 50 g a.i./ha. The use of synthetic pyrethroids showed early opening of bolls and less stained seed cotton. However, fenvalerate and cypermethrin (@ 40 and 30 g a.i./ha) also recorded lesser locule damage and higher seed cotton yield (Singh and Lakra, 1990a).

Venugopal Rao et al. (1990b) reported that in addition to controlling the incidence of sucking pests, deltaphos (triazophos 0.05 % + deltamethrin 0.002 %), acephate (0.1 %) and triazophos (0.1 %) also controlled H. armigera damage significantly and recorded highest seed cotton yield in deltaphos followed by acephate and triazophos.

Deltaphos (a mixture of deltamethrin and triazophos) at 270 g a.i./ha was found effective for bollworm control and also keeps the population of sucking pests below economic injury level. Deltaphos treated plots gave seed cotton yield equivalent to fenvalerate, cypermethrin and deltamethrin (Dhawan et al., 1991).

Gupta and Katiyar (1991) observed the physical compatibility between synthetic pyrethroids (deltamethrin
or cypermethrin) with organophosphate monocrotophos in a tank-mix spray and found effective in reducing the incidence of bollworms without any resurgence problem of whitefly and were economically suitable to cotton grown in North India. Whereas, maximum population of whitefly was in deltamethrin and cypermethrin treated plots.

Gupta et al. (1991) have recommended judicious use of synthetic pyrethroids and found that incorporating two sprays of synthetic pyrethroids in a spray schedule was economical and effective in reducing the incidence and increasing the quality yield significantly with maximum C : B ratio of 1 : 5.6 in monocrotophos, fenvalerate, deltamethrin and carbaryl spray schedule.

Singh (1991) tested four spray schedules and found that the spray schedule of 4 insecticides (dimethoate 0.04 % followed by monocrotophos @ 500 g a.i./ha, cypermethrin @ 75 g a.i./ha and endosulfan @ 750 g a.i./ha) and of 5 sprays (dimethoate, monocrotophos, cypermethrin, endosulfan and fenpropethrin @ 75 g a.i./ha) were found most effective in reducing jassid and bollworms without effecting nontarget soil arthropods (mites and saprophytic
collembola) with the C : B ratio of 1 : 6.0' and 1 : 4.37 in respective schedule. He also reported that schedules without synthetic pyrethroid was not so effective and economic.

Sudhaker (1991) tested conventional insecticides and synthetic pyrethroids in laboratory against *Helicoverpa armigera* on cotton. He observed that no chemical could provide more than 73 % mortality. Synthetic pyrethroids, cypermethrin 25 EC, fenvalerate 20 EC and deltamethrin 20 EC gave only 63.3, 46.7 and 20.0 % mortality of *H. armigera* larvae. He suggested that tolerance to insecticides particularly synthetic pyrethroids is being developed in *H. armigera* larvae.

2.8.3 Resurgence or secondary outbreak of sucking pests:

The synthetic pyrethroids, used frequently for the control of budworms and bollworms, were not found effective against sucking pests and even led to secondary outbreak or resurgence of aphid population (Murugesan *et al.*, 1979; Venugopal Rao *et al.*, 1990b), red spider mites (Rosaiáh *et al.*, 1980; Ramesh Babu and Azam, 1983), whitefly (Anonymous, 1980-84; Wangboonkong, 1981;
Johnson et al., 1982; Reddy et al., 1985; Anonymous, 1986 and 1991-92; Shekle et al., 1986; Thakare et al., 1986; Gupta and Katiyar, 1988 & 1991; Singh, 1991), mealy bug (Patel et al., 1983) and of aphid, whitefly and mealy bug (Surulivelu and Sundaramurthy, 1986). Singh (1991) also reported that resurgence of whitefly population was more in those plots in which synthetic pyrethroid ended with last spray.

2.9 Role of sex pheromones in monitoring and management of bollworms

The term pheromone was first proposed and defined by Karlson and Litscher (1959) and the first insect pheromone was identified by Butenandt et al. (1961). Karlson (1960) divided the pheromones into two groups (I) Olfactory and (II) Gustatory. Wilson (1963) divided the pheromones into two functional groups (a) Releasers and (b) Primers. The action of the releaser pheromones secreted by female is to attract male for copulation.

These sex pheromones have been synthesised in the laboratory (Jacobson, 1972). Synthetic pheromones are useful in locating opposite sex within the species and indeed, they are among the most potent and physiologically active substances known today. The use of these
chemicals in pest control has developed along three main pathways: monitoring of insect populations with pheromone baited traps; control by mass trapping using large number of traps to reduce population levels and control by mating disruption (Campion, 1983; Pawar et al., 1983).

Reddy and Rosaiah (1989) recommended plantation of sex pheromone traps @ 10 per hectare for mass trapping of male moths of bollworms. They advised to exploit mating disruption technique for the control of cotton bollworms in our country. They further added that it is a low cost technology with no deleterious effects like environmental pollution, development of resistance by insects and operational hazards. Moreover, it is compatible with insecticidal control. Hence, this novel approach may play a prominent role in future pest control strategies by intelligently integrating it with other tools to make the environment less suitable for survival or reproduction of agricultural pests. They further stated that synthetic pheromones which mimic the biological activity of these naturally produced are now-a-days commercially available for pink, spotted and green bollworms and are named as below:
Pink bollworm
(Pectinophora gossypiella) : Gossypiure, a 1 : 1 mixture of (7 Z, 11 E) and (7 Z, 11 Z)-7, 11-hexadecadienyl acetate or 1 : 1 mixture of (Z, E) and (Z, Z)-7, 11-hexadecadienyl acetates.

Spotted bollworms
(Earias vitella and E. insulana) : A 10 : 1 mixture of (E, E) - 10,12-hexadecadienal and (Z)-11-hexadecenal components.

Green or American bollworm
(Helicoverpa armigera ) : 97 : 3 blend of (Z)-11-hexadecenal and (Z)-9-hexadecenal components.

Some workers have used sex pheromones in monitoring and management of cotton bollworms.

2.9.1 Pink bollworm :

Synthetic gossypiure has been reported to be very effective in attracting pink bollworm male moths (Reed et al., 1975; Flint et al., 1977; Balasubramanian et al., 1979).

Igram (1980) suggested the timing of sprays to control pink bollworm on the basis of boll damage which is determined from the number of moth caught in gossypiure baited trap. He observed an increase in 10 per cent damage by a unit increase in moth catch. He advised to position the pheromone trap just above the canopy height. Taneja and Jayaswal (1987) also found positive correlation between per cent flower and boll damage and trap catches.
Dhanwan and Sidhu (1988) determined the correlations between moth catch in gossypolure baited trap and pink bollworm incidence in F 414 hirsutum cotton. The correlations were highly significant between moth catch and pink bollworm damage among bolls and loculi and larval population in bolls and shed material.

Siddiqi (1988) studied the trapping of pink bollworm with its' synthetic sex pheromone gossypolure. He observed that emergence of pink bollworm moths in cotton field started in third week of July (before flowering), increased at flowering time and reached to peak at boll bursting stage. Thereafter, there was a decline in moth catches. Low temperature (27.5 to 29 °C) and low humidity (35 to 57.5 %) were suitable for the emergence of moths.

Singh and Lather (1989) studied the seasonal occurrence of male pink bollworm from 1981 to 1985 at Haryana by means of sex pheromone traps. The moths remained active throughout the year with minimum intensity during May-June (summer) and January-February (winter). The main period of moth emergence from August to first week of October coincides well with effective boll setting in cotton variety H 777.
Karuppuchamy and Balasubramanian (1990) found the peak male activity of pink bollworm between 2 to 3 am at 120 days old crop (December) and between 3 to 4 am at 180 days old crop (February-March). There was a positive correlation between larval infestation in the field and trap catches.

2.9.2 American bollworm:

Synthetic pheromone of *Heliothis armigera*, which is 97 : 3 blend of (z)-11- Hexadecenal and (z)-9- Hexadecenal, has proved more effective than natural product of female for monitoring purpose (Pawar et al., 1983). On the basis of further investigations, Pawar et al. (1983) advised to use sleeve traps for monitoring *H. armigera*.

On the basis of experiments on the implications of sex pheromones in gram pod borer, Lal et al. (1985) concluded that sex pheromone trap is a convenient powerful tool and gives reliable catches for monitoring population densities of the pest and forecasting the outbreaks.

Gachan (1987) saturated the village Gadankhera (District Kanpur) with *Heliothis* pheromone traps @ 4 traps per acre in pigeonpea field. Moth catches were very
high in all these traps. He found pheromone septa quite potent for 23 days. However, he could not assess the impact of these traps on pest control.

Sinha and Jain (1992) recorded maximum male moth catches of *Helicoverpa armigera* in sex pheromone baited traps during the spring/summer season (6th to 28th std. week) while a minor peak activity was observed in autumn (42nd to 50th std. week). Pattern of trap catches indicated occurrence of 4 to 5 generations in a year. Moth catches were found to be positively correlated with larval counts. Mean air temperature of 13.2°C or a relative humidity of 80.3% were required to get at least one catch of moth in a week.

2.9.3 Bollworms:

Jayraj et al. (1985) advised to set 4 to 5 traps per acre and replace rubber septae in 3 to 4 weeks. They further stated that in this way, female moths are deprived of suitable mates and hence the perpetuation of next generation may be checked in cotton bollworms.

Gupta (1980-89) worked out the role of sex pheromones in the management of cotton bollworms in
Madhya Pradesh. He observed considerable reduction in the incidence of all three bollworms (pink, spotted and American) in pheromone treated plots as compared to untreated plots. He recorded similar number of catches in the treatments—four, six and eight septae per acre and stated that plantation of four septae per acre was equally effective and more economic.

2.10 Integrated pest management in cotton involving use of sex pheromones

The ecological imbalance created by the indiscriminate use of large amounts of chemicals and introduction of susceptible varieties have posed new challenges in the control of insect pests of cotton. For instance, in the Colorado River Valley, as a result of elimination of natural enemies of cotton pests and the degree of resistance obtained by the pests to pesticides, 14 to 24 applications were required for the season long-control of pink bollworm (Smith, 1975).

Despite of the recommendations, the cotton growers of Lam (Guntur) resorted to spraying the crop for more than 25 rounds inclusive 8-10 sprays of synthetic pyrethroids at narrow intervals. Further, farmers
ignored the importance of lethal concentrations and proper foliage cover. This all misuse caused outbreaks of white-fly, disruption of natural balance in cotton eco-system and finally cotton cultivation became uneconomic (Anonymous, 1980-84).

Hence, researches were needed to develop harmless pest management strategies. The investigations of sex pheromones of all three bollworms also opened a sphere for its inclusion in integrated pest management of cotton. The important work done on this aspect has been reviewed.

In an integrated approach to manage the population of pink bollworm, by using various combinations of Chelonus spp. and permethrin with pheromone gossypalure, Legner and Medved (1981) concluded that a combination of insecticide permethrin (0.23 kg a.i./ha) with gossypalure afforded the best results. Boll infestation was reduced to only 8.3 %, moth emergence to 14.7 per 100 bolls and significantly higher yield of 1205 kg lint per ha was received.

Butler et al. (1983) conducted field trials in Arizona and California to evaluate the effectiveness of aerial application of gossypalure and observed that
per cent damage caused by pink bollworm was less than or about the same as that of cotton receiving treatment with recommended insecticides.

Critchley *et al.* (1987) reported a successful IPM in cotton with sex pheromones in Pakistan. A sex pheromone comprised of 1:1 mixture of the \((Z,E)\) and \((Z,Z)\)-7, 11 hexadecadienyl acetate components of *Pectinophora* and a 10:1 mixture of the \((E,E)\)-10, 12-hexadecadienial and \((Z)\)-11-hexadecenal components of *Earias vitella* and *E. insulana* were formulated for land application by Mitsubishi as a rope or twist-tie. This twist-tie formulation followed by a single insecticidal application at pin-square stage of cotton achieved almost complete suppression of all three species up to eight weeks.

On the basis of the trials conducted at various research stations of Indian Council of Agricultural Research, it was reported that integrated pest management involving the use of sex pheromones was effective in the management of bollworms in cotton in the northern, central and southern zones of India (Anonymous, 1991-92).