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Biological Parameters of Pink Bollworm *pectinophora gossypiella* (Saunders) (Lepidoptera:Gelechiidae): A looming Threat for Cotton and its Eradication Opportunity

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ABSTRACT

Pink bollworm Pectinophora gossypiella (Saunders) (Lepidoptera: Gelechiidae), is a worldwide key pest of cotton and its larvae burrow into cotton bolls to feed on the seeds. Early in the season, eggs are laid in any of the sheltered places of the plant axis of petioles or peduncles, the underside of young leaves and on buds or flowers. Once the bolls are 15 days old, these become favored sites for adult's oviposition. First two larval instars are white, while from third instar pink color develops and lint of pink bollworm attacked bolls is of inferior quality. The feeding damage allows other insects and fungi to enter the boll and cause additional damage. When the larva exits from the cotton boll, it leaves a perfectly round and clean cut exit hole which is diagnostic of pink bollworm damage. Cultural control plays a key role in keeping down the number of pink bollworm carry-over between cotton crops. Maintenance of host free period during off-season is an essential option to ensure a pink bollworm free next cotton season. Therefore, effective measures of preventing pink bollworm damage include post-harvest, off-season and pre-planting actions. Allowing cattle grazing of the left over green bolls on the plant at the end of crop season, timely crop termination to maintain closed season, clean up or destruction of cotton stubbles immediate to harvest, avoiding stacking of cotton stalks for fuel purpose over long periods and summer deep ploughing to expose thepupae of the surviving larvae constitute post-harvest and off season cultural measures. These practices adopted on a field-to-field basis over large areas of cotton growing regions by the cultivators would largely bring down the attack of pink bollworm in the ensuing season. While planning for the next season, selection of varieties with early maturity, drying of seeds under sun for 6-8 hours and sowing of acid de-linted seeds are effective and economical to prevent the carryover of pink bollworm to the next cotton season.

Keywords: *Pink bollworm, Pectinophora gossypiella, Cotton, Pest control*

INTRODUCTION

In cotton crop, a complex arthropod group may be composed of three trophic levels viz., primary consumers, parasitoids and hyperparasitoids, and predators. A primary consumer like bollworms entering in an ecosystem with a high density and species rich arthropod complex, may experience a damped density response. Among the primary bollworm complex are *Helicoverpa armigera* (Hubner), *Earias vittella* (Fab.), *E. insulana* (Boisduval), *Spodoptera litura* (Fab.) and *Pectinophora gossypiella* (Saunders) (Sarwar, 2016; 2017). Moths of genus *Pectinophora*are numerically a small group of the family Gelechiidae, which contains three species, *P. gossypiella* (Saunders), *P. scutigera* (Holdaway) and *P. endema* (Common). All species of *Pectinophora* are potential pests because they feed upon the buds, flowers and seed capsules of malvaceous plants. The list of hostplants for pink bollworm is extensive and there in *P. gossypiella* and *P. scutigera* are pests of cotton, while*P. endema* attacks hibiscus but not cotton. Moth *P. gossypiella* has become a commercial problem because its larval stage frequently enters diapause while in seed capsules, which enables the pest to become widespread. In contrast the spotted bollworm does not enter larval diapause within seed capsules and therefore has not become widespread (Bellows and Fisher, 1999).

Life Cycle of Pink Bollworm

Life cycle of pink bollworm, includes four development stages. These are the egg, larva, pupa, and adult. The time of life cycle required from egg to egg varies because of temperature and other conditions, but generally it is about one month during the summer months. It is only the larvae of pink bollworm that cause failure of buds to open, fruit shedding, lint damage and seed loss.

Life History of Pink Bollworm

Eggs are pearly iridescent white, flattened, oval measuring approximately 0.5 mm long, 0.25 mm wide and sculptured with longitudinal lines. Eggs are laid singly or in groups of four to five. First two instars are white, while from third instar pink color develops. The larvae have the characteristic dark brown head due to the sclerotized prothoracic shield. Pupae are light brown when fresh, gradually become dark brown as the pupation proceeds. Pupa measures up to 7 mm in length. The adult moth is greyish brown with blackish bands on the forewings and the hind wings are silvery grey. Moths emerge from pupae in the morning or in the evening, but are nocturnal, hiding amongst soil debris or cracks during the day. Larva when attacks the bud of less than 10 days old, shedding of bud occurs and larva dies. But with older bud, larva can complete development. There can be cent percent pink boll worm infestation on bolls, but there need not be any shedding. Larva in flower bud spins webbing that prevents proper flower opening leading to ‘rosetted-bloom’ or ‘rosetted-flower' (improper opening of petals) which is a typical sign of bollworm attack (Fig. 3). Ten to twenty days old bolls are attacked from under bracteoles. Larvae feed on the developing seeds. While in younger bolls entire content may be destroyed, in older bolls development could be completed on three to four seeds (Fig. 4). Inter-loculi movement is also seen in this pest. Sometimes, several larvae can infest a single boll. Small exit holes (smaller than the feeding holes of other two bollworms viz., *Earias* and *Helicoverpa* are seen on developing green bolls. Stained lint around feeding areas resulting in bad quality lint is seen in open bolls. Improper boll opening with damaged seeds are frequently obvious. Small round holes are seen on the septa between locules of open bolls (Kabissa, 1990).

The mature larvae are either 'short-cycle' and will go on to pupate or 'long cycle' to enter a state of diapause. In hot regions, short cycle larvae pupating may cut a round exit hole through carpel wall and fall to ground or may tunnel the cuticle, leaving it as a transparent window and pupate inside. Pupation is inside a loose fitting cocoon with a highly webbed exit at one end. Pupal period ranges between 8 and 13 days and the life cycle is completed in 3-6 weeks. Late season has invariably overlapping broods. The long cycle larva entering diapause, spins a tough thick walled, closely woven, spherical cell referred as ‘hibernaculum’ with no exit hole. Always, the long-term larvae occur during end of crop season, where there are mature bolls present and larvae often form their hibernaculae inside seeds. Hibernacula may occupy single seeds or double seeds. Pest *P. gossypiella* hibernate as full fed larvae during cold weather. Diapause larvae often spin up in the lint of an open boll and if still active in ginnery, will spin up on bales of lint, bags of seed or in cracks and crevices. Moths emerging from the hibernating larvae are long lived with females and males alive for 56 and 20 days, respectively. Insect is highly adaptable to different climatic conditions and larvae hide over unfavorable season inside empty cotton seed in which they are well protected and remain alive for many months. Survival of the pest from one season to another is entirely through hibernating larvae in seeds, soils and plant debris. Incidence of *P. gossypiella* during the season commences from the moth emerging from the over wintering larvae through the summer season. This is the only pest, which peaks at crop harvest. Depending upon the periods of crop maturity the seasonal dynamics, incidence and infestation levels vary. The effective population buildup starts after 100 to 110 days of crop emergence, while the peak infestations occur after 140 days. The crop with late maturity suffers heavy attack with 50-75% of the bolls showing damaged locules in open bolls. The higher damage levels despite lower incidence arise due to less number of bolls available at the end of season. If the pink bollworm appears early in the crop season due to favorable weather conditions, the damage is much more intensive during late season (Jha and Bisen, 1994; Sarwar et al., 2013).

Description of Insect’s Life Stages

During its life cycle, pink bollworm undergoes complete metamorphosis and is called holometabolous. After hatching from egg, the larva looks dramatically different to the adult insect and it must go through a pupal stage before its development into an adult.

Adults

Adult moths of *P. gossypiella* are small, about 5 mm in length dark-brown in color measuring about 12-20 mm across the wings. The head is reddish brown in color with pale, iridescent scales. Antennae are brown and the basal segment bears a pecten of five or six long, stiff, hair-like scales. The labial palpi are long and curved upwards, the second segment bears a slightly furrowed hairy brush on the underside that becomes smooth distally and the terminal segment is shorter than the second. The proboscis of adult pink bollworm is scaled. When their wings are folded, they have an elongated slender appearance. The wing tips are conspicuously fringed. Forewings are elongated, oval, pointed at the tips and bearing a wide fringe. The ground color of the forewings is brown and they have fine dark scales that form vague patches in the region of the medial cells and at the wing base. The apical portion of the wing is dark brown with a transverse, light-colored band. Sometimes the wing bears a round medial spot. Forewing is much longer than wide, with a fringe of hair-like scales beginning from the middle of the posterior edge of the wing, continuing around the tip. The forewing terminates in a pointed tip that may be obscured by the fringe scales which may give the appearance of a flat-tipped wing. The hind wing has broad fringe about as long as the width of the wing along the hind margin and curving around to the anterior margin where it is no more than half the width of the wing in length. The distal end of the hind wing has a sigmoidal or‘s-shaped’ curve producing a sharp point on the anterior edge. The hind wings are broader than the fore wings, trapezoidal in form and silvery grey with a darker, iridescent hind margin. The wing fringe is ochreous and darker at the base and apex. Adults emerge as brownish or grayish moths with dark mottling and dark spots on their wings (Fig. 1) (Zhang, 1994).

Legs are brownish black with transverse, ochreous bands in the form of rings. The abdomen is ochreous toward the upper side, dark brown laterally and covered with ochreous-brown scales on the underside. In the genitalia, the male uncus is broad at the base, tapering to a point and the aedeagus has a hooked tip. The female ovipositor is weakly sclerotized. They emerge from pupae in an approximately 1:1 male to female ratio. There is a time period of two to three days after emergence during which the female mates and prepares to lay eggs. After this preoviposition period the female lays most of her eggs in about ten days. Both male and female adults feed primarily on nectarines located on the bottom of cotton leaves and may live for one to two months. The female produces a sex pheromone that aids the male in locating it for mating purposes.

Eggs

Normally, the pink bollworm females take two or three days to mate and develop eggs within its body. After this brief period she lays the majority of her eggs within ten days. Eggs are laid on flowers, young bolls, axils of petioles and underside of young leaves. Female moths lay eggs singly or more commonly, in small groups. Eggs are elongated-oval, 0.4-0.6 mm in length and 0.2-0.3 mm wide. These are usually laid singly, or in groups of 5-10. Eggs are white when first laid, but then turn orange and later the larval head capsule is visible prior to hatching. The eggs are small and difficult to see without some magnification. Eggs of the first field generation in the spring are often laid on vegetative cotton plants near cotton squares and sometimes on squares. Second and subsequent generation eggs are usually laid under the calyx of bolls. Eggs are also laid under the bracts of cotton bolls. Pink bollworm eggs take about three to four days to hatch after they are laid. They are white at first and progress to an orange color as development progresses (Fig. 2). Gergis et al. (1990) showed that eggs require temperatures between 10 and 37.5°C to hatch. The developmental rate of all stages increases with temperature, up to 37.5°C where mortality rises.

Larvae

From eggs which are very small, slightly elongated, and laid under the calyx of green bolls hatch into pale colored larvae. Larvae are 1-2 mm long when they first hatch and mature larvae are 12-15 mm long with a prominent pinkish coloration. Young larvae are tiny, white caterpillars with dark brown heads. They do not turn pink until the fourth and last larval stage. When mature, they have wide transverse pink bands on the back. Larvae turn pink in color in 3-4 days after hatching. To be able to see pink bollworm larvae, bolls have to be cracked open. The first and second instars are difficult to see against the white lint of the bolls. Larvae bore into the cotton plant usually in the cotton boll in order to feed on the seeds. The larva moves from seed to seed within the boll, chewing through the cotton fibers as it goes. Larvae take twelve to fifteen days to develop, after which they move to the soil to pupate. The brown pupa remains immobile in the top layer of the soil for seven to eight days (Fig. 5).

Larvae immediately begin to bore into squares or bolls after hatching. In squares, larvae complete most of their development before blossoming occurs and often cause rosetted blooms. Final development is completed in the blossom. In bolls, larvae feed within one to five seeds to complete development before exiting and dropping to the soil for pupation. While moving from seed to seed, the larva causes damage by cutting through the lint with its mouthparts. Lint is also damaged as the larva tunnels out of boll. After hatching, the young larvae can also penetrate ovaries of flowers or young bolls within two days of hatching. The degree of pink color depends on the food that the larvae eat and dark pink results from eating of maturing seeds. Larvae prefer feeding on developing seeds and generally pupate inside the seeds and bolls. Affected bolls either open prematurely or get badly affected due to rotting. Fiber qualities such as length and strength are lowered. Further the cotton lint in the insect infested bolls gets damaged by secondary fungal infection. The seed cotton carried to market yards acts as a source for the pest to spread.

Pupae

It is in pupation that the pink bollworm makes the drastic transformation from a larva to an adult moth. Pupae are reddish-brown and approximately measure 8-10 mm in length. Most pupation occurs in the top layer of soil beneath cotton plants and is brown in color. It does not feed or move about during the pupal period of seven to eight days (Fig. 6).

Fig1. *Adult*

Fig2. *Eggs*

Fig3. *Rosetted bloom*

Fig4. *Larva feeding on boll*

Fig5. *Late instar larva*

Fig6. *Pupa*

Host Plants Attacked/ Species Affected

The pink bollworm larva is an oligophagous pest feeding on the blossoms, lint and seeds of cotton, and may pupate in the buds. The larvae feed only on a few crops such as cotton, *Abelmoschus esculentus* (okra), Hibiscus and jute. In a survey of okra, deccan hemp (*Hibiscus cannabinus* [kenaf]) and roselle (*H. sabdariffa*) in autumn, *P. gossypiella* has been found to prefer okra over cotton towards the end of the season when the cotton boll surface is hard. Other alternative host plants/ species affected by this pest are, *Abutilon* (Indian mallow), *Abutilon indicum* (country mallow), Althaea (hollyhocks), Gossypium (cotton), *Gossypium arboreum* (cotton, tree), *Gossypium herbaceum* (short staple cotton), Hibiscus (rose mallows), *Hibiscus cannabinus* (kenaf), *Hibiscus sabdariffa* (Jamaica sorrel), *Thespesia populnea*, Malvaceae and *Medicago sativa* (lucerne). Pink bollworm causes external feeding on inflorescence, while internal feeding on fruit resulting black or brown lesions, and attacked buds failure to open, fruit shedding, lint damage and seed loss (Khidr et al., 1990).

Seasonal Cycle of Pink Bollworm

Understanding the seasonal cycle of this pest species is key to exploite cultural control techniques which can be responsible for season long control of the pink bollworm. The seasonal cycle is intimately tied to the cultivation of our cotton crop, because domestic cotton is the only host through most of the pink bollworm's range.

Winter Cycle

The pink bollworm overwinters as a fully developed larva (fourth instar).During this period the pink bollworm is in a state of arrested development called diapause. The larva often spins a loose, silken web or cocoon in which it remains until the late winter and spring. Overwintering larvae may be found in bolls in the soil or on plants which remain un-ploughed through the winter. Often times the larvae may be found within the hollowed out seeds of undestroyed bolls. The larvae may also be found directly in the soil outside of seeds or bolls. In some regions, about 50% of diapausing larvae live through the winter in the silken cocoons in the top two to three inches of soil while the other 50% remain in whole or fragmented bolls and squares (Parmar and Patel, 2016).

Spring Cycle

Once diapause is completed, the larva begins to respond to temperature and moisture conditions, and ultimately pupates in the spring. Though moths may be captured virtually during any month of the year, most adults will emerge from pupae with in the soil in the spring. Adults must navigate through the cracking soil in order to emerge, dry their wings and start the first field generation. Adults move about searching for cotton and are capable of travelling long distances in order to reach susceptible cotton. Most flight occurs at night (especially midnight to 3 a.m.) when temperatures and wind conditions are moderate (i.e., > 50°F and < 10 mph). Mating occurs and a gravid female must lay most of its eggs in about 10 days after emerging. Squares which are capable of supporting pink bollworm larvae are deemed susceptible. This condition occurs when the sepals first part and the white petals become visible. Usually this corresponds to a 10-day old square. Up to this point of cotton development, pink bollworm cannot successfully colonize cotton and will perish. This is termed 'suicidal emergence'. Thus, adult moths that emerge about ten days or more prior to susceptible square die without contributing to the first field generation. Larvae from eggs laid on susceptible squares feed inside the squares and often cause rosetted blooms. Rosetted blooms are flowers which have had their petalstied together with silk by the developing larva. Most of the feeding at this stage is concentrated on the developing pollen grains and other floral parts. This can interfere with the proper development of the new boll. Occasionally, the larva can travel to the bottom of the flower and begin feeding at the tip of the newly developing boll (Karsholt and Razowski, 1996).

Summer Cycle

Fully developed larvae drop to the soil and pupate for seven to eight days before emerging as second generation moths. Each generation during the summer takes about 750 heat units (base 55°/86°F). This period is roughly equivalent to about one month in the low deserts. Depending on local conditions, pink bollworm is capable of passing through from one to four summer generations. The greater the number of generations that are possible for an area or allowed for by production decisions, the greater the chance is that damaging numbers will build-up. Once present on the plant, bolls become the preferred egg-laying site and feeding medium for the larvae (Chaudhari et al., 1999).

Fall Cycle

Some larvae begin to prepare for winter diapause in late August and this diapause accelerates rapidly after mid-September as day lengths begin to shorten. Diapause is caused primarily by shorter days (reduced photoperiod) and lower temperatures (≤70°F) and therefore it predictably occurs at about the same time each year. A reducing percentage of pink bollworms continue to re-cycle throughout the fall months and they can cause late season infestations. Limiting the number of small green bolls present after mid-September can drastically reduce the number of sites for pink bollworm re-cycling and overwintering. By late fall, if bolls are present, it is not unusual to have multiple larvae per boll present. These latest bolls on the top of the plant are generally immature, have poor lint characteristics and contribute little or nothing to yield (Chaudhari et al., 2006).

Nature of Damage by Pink Bollworm

In financial terms, pink bollworm is one of the most damaging pests of cotton. It is the worst enemy of cotton which not only causes loss to crop, but also affects the lint quality. Pink bollworm generally arrives with the onset of winter and continues to survive on the crop as long as flowers and bolls are available. Long duration cotton allows the pest to thrive for a longer continued period in multiple cycles, thereby affecting the subsequent cotton crop. In the absence of cotton, or as a genetically pre-disposed condition, the pink bollworm undergoes hibernation or diapause that allows it to be dormant for 6-8 months, until the next season. Pink bollworms damage squares and bolls, the damage to bolls being the most serious. Larvae burrow into bolls, through the lint, to feed on seeds. As the larva burrows within a boll, lint is cut and stained, resulting in severe quality loss. Under dry conditions, yield and quality losses are directly related to the percentage of bolls infested and the numbers of larvae per boll. With high humidity, it only takes one or two larvae to destroy an entire boll because damaged bolls are vulnerable to infection by boll rot fungi. Along with the yield reduction, it also damages the lint quality by causing yellow spots in its fiber. The pink bollworm larvae feed on the seed and affect the germination quality of the seed. The loss in weight of seed cotton will be there. The oil content is also affected. In fact, pink bollworm also reduces the oil content and quality of cake. Moreover, the damaged seed does not germinate. Stained lint in open bolls is a distinct symptom of damage. It occurs in the later stages of crop growth, once the damage is done (Arshad et al., 2015).

During active season, pink bollworm completes four generations on cotton and the larvae of the fifth generation start entering diapauses when temperatures start falling. Diapause is a state in which the insect remains inactive for months due to the climatic conditions or the lack of food. Its activity is a complex phenomenon affected by oil contents, temperature and the day’s length. Most of the leftover bolls on cotton sticks have diapausing larvae at the end of cotton season. Such bolls do not open and stay on cotton sticks. They are the main source of carry-over of pink bollworm from one season to another. Pink bollworm larvae hatched from the eggs take 30-60 minutes to enter the fruit. Most of these enter through the base of fruits, leaving no mark of entry. Larvae do not survive if an infested fruit sheds at an early stage. It continues to feed on internal parts of fruit and later stitches the petals together, preventing the flower from opening. In green cotton bolls, larvae generally enter through the tip of 14-28-day old bolls leaving a yellow spot on the lint at entry point. It feeds on the boll contents, including the lint near the entry point at least for 24 hours. It feeds on lint, seed coat and kernel completely before attacking the second seed. Two seeds are sufficient to complete larval development, but some of the population also feeds on more seeds within the same boll. A week old infested boll remains attached to the plant and dries up. If the boll is attacked when it is half-grown, it does not shed, but exhibits partial damage and early opening. The rate of infestation varies considerably and depends mainly on climatic factors such as the temperature and rainfall. Frequent rains during August and September provide favorable conditions for pink bollworm infestation. Its larvae leave the bolls for pupation on soil during different times of the day. Maximum number leaves the bolls for pupation during midday, around 1200-1300 hours and almost 69-75 per cent larvae come out of bolls between 1100 to 1500 hours when the temperatures are at their highest. The rate of dropping to the ground decreases gradually after 1500 hours and the decrease is at its minimum at night. Pupation occurs either in the top 5 cm of soil or in the soil crevices, mostly under the plant periphery. Pupation period is 6-10 days during the summer season. In November, larvae enter diapauses in the bolls or in the soil until conditions become suitable for their emergence and for starting a new life cycle. Depending on the extent of infestation and weather conditions, this pest can cause about 20 to 30 per cent crop loss (Silvie and Goze, 1991; Mallah et al., 2000).

Insect Pest Management

Pink bollworm is usually a mono-host pest and hence can be easily managed provided all necessary precautions are taken. When high population levels of pink bollworm occur, the objectives of management are to keep infestations below damaging levels in the current season without creating secondary outbreaks of other pests and to reduce the overwintering population that will threaten the following season's crop. The main control tools are observance of host-free period, the judicious use of insecticides, timely crop termination and harvest, rapid crop destruction, properly timed winter and spring irrigations, and compliance with plough down requirements. When pink bollworms are found in a valley, a regional monitoring and sterile moth release program is implemented. Chemical control is difficult because the insect spends most of its time within the fruiting bodies and is not exposed to direct chemical spray. Only pesticides with good residue can help in controlling of the pest at egg-hatching stage, which means 4-6 sprays at weekly intervals. Excessive use of pesticides always results in a flare up of secondary pests like army worm, cotton bollworm and spider mites because sprays perish most of their natural enemies (Beasley and Adams, 1995).

Scouting and Threshold

Cotton insect scouting is the regular and systematic inspection of cotton for insects and their damage. Its purpose is to obtain an accurate estimate on the types and numbers of important insects and their damage in the field by checking a limited number of plants or plant parts. Threshold is the level of plant damage or the number of insects at which treatment is recommended, hopefully the point at which the benefits of control will outweigh the costs. Threshold numbers are usually expressed in terms of the percentage or number of insects or instances of injury or damage seen per 100 forms inspected. The economic threshold of damage for the pink bollworm is either 17 larvae or 11% infestation/100 green bolls. Prior to first bloom, once pheromone traps exceed an average of 5 moths per pheromone trap per night, then a treatment is justified to prevent pink bollworm establishment. Treatment applications at pinhead sized square to 1/3-grown square stage may be insecticidal, pheromone mating disruptors, or a combination of these treatments (Ahmad and Sarwar, 2013).

Biological Control

During the last some years, bollworm *P. gossypiella* has been a target for biological control option. Several groups of arthropods attack pink bollworm naturally, including mites, predaceous Dermaptera, Hemiptera, Coleoptera and Neuroptera. The egg stage is most vulnerable to attack by predators because it is relatively exposed when compared to larvae and pupae. Most predators lack morphological modification of the legs and mouthparts necessary to penetrate bolls to feed on pink bollworm larvae. The dermapteran *Labidura riparia* (Pallas) attacks all immature stages of pink bollworm including the pupa. There has been found 22 parasites of *P. gossypiella* in a survey in Pakistan, of these, only *Apanteles angaleti* is a major larval parasite, while, other are Bracon *Chelonus curvimaculatus* and *Microchelonus blackburni*. Predators and parasiteson eggs or larvae are common; *Trichogrammatoidea bactrae* or *T. chilonis* parasitize eggs, *Zelus renardii* is predator, *Pardosa milvina* and *Polybia ignobilis* are adult's predators as well as Orius and Nabisalso predate. The genera *Apanteles*, *Bracon* and *Chelonus* among the Braconidae contribute numerous species of parasitoids. Coleoptera are well represented with four species in four genera attacking pink bollworm, herein most of beetles focus on eggs and early in star larvae as prey. Pathogen *Bacillus thuringiensis* and more recently nematodes have been used as control agents (Henneberry et al., 1996; Gouge et al., 1999; Sarwar, 2013 a; 2013 b).

Pheromonal Control

Pheromones are scents that are released generally by female insects to attract male insects. These scents are synthesized artificially and used in traps to monitor the onset and levels of infestation. Pheromones at higher dosages or frequency of lures can also be used in mass trapping and to confuse mating. The best control of pink bollworm has been demonstrated with the use of pheromone. A good correlation has been obtained between the pheromone trap catches and larval incidence in the field. Fields treated with pheromone also have a higher population of predators and parasites that are an important component of integrated pest management. Fields where pheromone products are applied have negligible moth activity compared to chemically controlled cotton fields. Because of the danger of secondary outbreaks, especially in the low desert valleys, it is wise to limit insecticide treatments to those periods when susceptible bolls are present and when sampling shows the percentage of infested bolls is above the treatment threshold. It is rarely necessary to apply insecticides against moths from the overwintered population of pink bollworm and, often, treatments are not needed against the first generation of moths that develop from larvae within squares. However, pay attention, for high populations of pink bollworm moths when squares are developing, especially if other pests such as bugs and armyworms are also threatening. Mating disruptants and sterile moth releases, on the other hand, are most effective when aimed at the overwintering generation, usually about the time when cotton plants have 6 to 8 leaves (Howse et al., 1998; Shah et al., 2011; Khalid et al., 2015).

Synthetic pheromones have been employed extensively in the detection and control of *P. gossypiella*. Trapping with the synthetic pheromone gossyplure has been widely used and is reported to have resulted in a 60-80% reduction of the pest population (Gao et al., 1992). Pheromone trapping has also been used for an attempted eradication program and the pheromone has been found to enhance the efficacy of insecticides. Busoli (1993) has reported that the use of the sex pheromones gossyplure and virelure are more economically viable than the use of conventional insecticides. Early-season use of pheromone coupled with insecticides applied at low thresholds is generally most profitable, especially at low pink bollworm population densities. The pheromone has been included in an integrated pest management program in an attempted eradication program, however, gossyplure is not effective in all cases. Mabbett (1991) reports that in Pakistan a different pest complex on cotton, including Earias spp., requires higher levels of pesticides early in the season which negates the usefulness of the pheromone. Moreover, early trials using gossyplure to saturate the cotton environment with pheromone in an attempt to disrupt the location of females by males proved inconclusive, but few researchers, Boguslawski and Basedow (2001) found that mating disruption gave more effective control than insecticides. For monitoring pink bollworm infestation on the crop, this can be done easily through the use of gossyplure pheromone baited traps that attract the males. Once few male moths are found in the traps, it is an indication of the incidence starting in the bolls of the cotton plants. One approach of pink bollworm suppression is to trap most of the male moths in the crop ecosystem by using large number of pheromone traps (@ 20 number/ha, so that mating is disrupted and the population development is arrested. The Delta pheromone trap is more efficient in capturing of *P. gossypiella* than with the PET pheromone trap. Nocturnal activity peaks have been found to be related with the time of year and it occurs between 11:00 p.m. and 2:00 a.m. Do not apply insecticides to control larvae, because larvae are either inside the boll or in the ground and therefore insecticide contact is difficult. For this method to be effective traps should be placed over many fields over larger areas. Since the damage and stages of pink bollworm are not visible, the decision of insecticidal spray is arrived at using the male catches in the traps. If the moth catches exceed eight per trap for three consecutive days an insecticidal spray in the field is desired. When much of the bolls on the plants are 20-25 days old, then insecticidal protection is essential. In the absence of pheromone traps, assessment of pink bollworm damage should be based on destructive sampling (boll cracking method) and chemical spray should be taken up when two live larvae are found in 20 medium sized green bolls sampled per acre (Jaleel et al., 2014; Khanzada et al., 2016).

Sterile Male Release

A comprehensive sterile male release program can be conducted in cotton areas, and, despite of the controversy surrounding this method, pest infestations there have been remained at low levels. Sterile insects are released into the environment in very large numbers (10 to 100 times the number of native insects) in order to mate with the native insects that are present in the environment. A native female that mates with a sterile male will produce infertile eggs. Since there are 10 to 100 times more sterile insects in the population than native insects, most of the crosses become sterile. As the process is repeated, the number of native insects decreases and the ratio of sterile to native insects increases, thus driving the native population to extinction. Radiation-induced F1 sterility has also been investigated as a possible means of control. Conditionally, lethal strains of pink bollworm expressing partial mortality have recently been developed with RIDL (Release of Insects with Dominant Lethality) technology as a control strategy using genetically engineered insects that have (carry) a lethal gene in their genome (an organism's DNA). Lethal genes cause death in an organism, and RIDL genes only kill young insects, usually larvae or pupae (Ahmad et al., 2011)).

Cultural Control

Cultural practices affecting the survival of pink bollworm have been extensively investigated and found to have an important role in reducing of overwintering populations. Researchers have reported more than 80 percent reduction in moth emergence from fields that have been shredded and plowed. Diapausing larvae over winter in immature cotton bolls, trash, and soil. The removal of late-season immature cotton bolls is a viable option to reduce the overwintering population. Cultural control techniques that include shredding stalks, disking, ploughing and winter irrigation have been shown to result in high levels of mortality of diapausing larvae in bolls, trash and soil. Follow clean cultivation and destruction of crop residues (fallen leaves, twigs etc.) before the onset of season, and plough deeply to expose the hibernating larvae/pupae to hot sun. Late planting of crops has been used as a cultural control method where the end of diapause is triggered by day length. Larvae that emerge before the crop is ready then have no food supply. However, avoid late sowing, i.e., do not take up sowing after July first fortnight (Ferre and Van Rie, 2002). Eliminate the food supply for pink bollworm by cutting off irrigation early enough to stop production of green bolls by early September. Regardless of when the crop is terminated, immediately shred the cotton plants following harvest. Winter irrigations can reduce populations of overwintering pink bollworms by as much as 50 to 70%; flooding in December is more effective than flooding in November or January. The use of *Bt* cotton will help to prevent damage by pink bollworm. Few recently developed transgenic cotton, can offer suppression of cotton bollworm, along with beet armyworms, pink bollworm and tobacco budworm (Tabashnik et al., 2002). Novo and Gabriel (1994) reported that gin trash is a carrier of pests and that cotton seed mills with adequate fans for the expellation of gin trash have fewer cotton pests than mills without this equipment.

Control of Pink Bollworm by Transgenic Cotton

Crops genetically engineered to produce *Bacillus thuringiensis* (Bt) toxins for insect control can reduce use of conventional insecticides, but insect resistance could limit the success of this technology. Genes from the bacterium *B. thuringiensis* that produce the Cry1Ab or CrylAc proteins that are toxic specifically to lepidopterous insect species are inserted into cotton plants. The first generation of transgenic cotton with *B. thuringiensis* produces a single toxin, Cry1Ac, which is highly effective against susceptible larvae of pink bollworm. In particular, Bt cotton provided an exceptionally high level of season-long control of pink bollworm. To counter potential problems with resistance, second-generation transgenic cotton that produces *B. thuringiensis* toxin Cry2Ab alone or in combination with Cry1Ac has been developed. However, the pink bollworm developed resistance to two Cry toxins deployed in Bt cotton. Seed companies must ensure that Cry toxins are present in the hybrids in homozygous form, instead of the segregating heterozygous form as in the current hybrids (Godoy-Avila et al., 2000; Perlak et al., 2001). Another strategy for overcoming this is the use of refuges in which non-transgenic plants are planted nearby (Tabashnik et al., 1999), or else a strategy of inter-planting one non-transgenic row in five lines is used (Simmons et al., 1998).

Organically Acceptable Methods

Cultural controls, with the exception of the use of *Bt* cotton and the use of mating disruption and sprays formulation of spinosad are acceptable to use on organically grown cotton. The simplest and most potent way to overcome the problem is to take up timely sowing and cultivate early maturing short duration varieties of about 150 days duration. All other management strategies such as avoidance of excess urea + OP insecticides, use of light traps, pheromone traps, biopesticides, biological control etc., can rally around such varieties to minimize the damage to zero levels. Carry out regular monitoring of bollworm resistance to Bt cotton and use of the parasitoid *Trichogramma bactriae* in Bt cotton fields for pink bollworm management. It is recommended planting of conventional non-Bt *G. hirsutum* cotton and late planted okra as refugia crops. Take timely termination of the crop latest by December and avoiding ratoon or extended crop. Perform utilization or destruction of crop residues and cotton stalks immediately after harvest. Crop rotation is strongly recommended to break the pest cycle. Short duration single-pick varieties (150 days) provide high yields in high density and escape the pink bollworm. Installation of light traps and pheromone traps in fields during the season and also near go-downs, ginning mills, market yards etc., to trap post season moths (Moar et al., 1994; Sandhya et al., 2010).

Pesticide Control

Insecticide applications have eventually eliminated attempts to biologically control pink bollworm in certain states of world. Insecticides represent the primary control measure which has been successful in limiting damage of pink bollworm in commercial cotton. However, during more than forty years of application, insecticides have not solved the problem anywhere in the world. Each cotton growing season has found pink bollworm presenting and developing resistance to toxic compounds. Actually, insecticidal control is hindered by the larvae being internal feeders; moreover, resistance to insecticides developed making it often more expensive than other methods. Nonetheless, there is an extensive literature on chemical control, especially from subcontinent. The efficacies of asymethrin, chlorpyriphos, synthetic pyrethroids, fenpropathrin, teflubenzuron, carbaryl, cyhalothrin, fluvalinate, esfenvalerate, indoxacarb (steward), spinosad, lambda - cyhalothrin, thiamethoxam and fenvalerate have been tested. When a determined economic damage threshold of the pink bollworm is reached the application of selected chemical insecticides is justified. Pink bollworm moths are generally most active between midnight and 3 AM, thus late afternoon or evening insecticide applications tend to be more effective than those applied in the morning (Tadas et al., 1994; Sarwar and Sattar, 2016).

Integrated Pest Management

Integrated Pest Management (IPM) also known as Integrated Pest Control (IPC) is a combination of common sense and scientific principles. It is an ecosystem-based strategy that focuses on long-term prevention of pests or their damage through a combination of techniques such as biological control, habitat manipulation, modification of cultural practices and use of resistant varieties. Combinations of biological and chemical controls have also proved successful. It has been found that application of *Trichogramma chilonis* Ishii in combination with chemical insecticides can give good control of pink bollworm, and *Bacillus thuringiensis* has been found to be effective in combination with chemical insecticides. Integrated control uses the release of sterile insects, cultural controls, intensive monitoring with pheromone baited traps for adult males and boll sampling, pheromone applications for mating disruption, very limited use of pesticides and the widespread use of genetically engineered cotton (Walters et al., 1998). In Pakistan, Ahmad et al., (2001) found a combination of biological control and mating disruption techniques to be effective.

Conclusion

The red colored larva of pink bollworm, is a serious concern for cotton farming by nourishing inside of fresh and fully grown bolls and feeding on developing seeds. Adult moths lay most eggs within 10 days, are laid under the calyx and hatch in 3-4 days. Larval stage is 12-15 days and pupal stage lasts for 7-8 days. The damage is more especially in the green bolls for second and subsequent pickings. Through out spring, the emerging moths lay eggs on susceptible squares where larvae cause rosetted blooms. Each summer generation takes about 1 month and larvae can be found near mines, warts or seeds in bolls. During winter larvae overwinter protected in soil, bolls, or cotton debris. The small green bolls in the fall provide an ideal habitat for larvae preparing for the winter. After hatching, the young larvae penetrate ovaries of flowers or young bolls with in two days of hatching and turn pink in color in 3-4 days after hatching. Moths are dirty brown in color and dark pink larvae result from eating of maturing seeds. Larvae prefer feeding on developing seeds and generally pupate inside the seeds and bolls. Attacked flowers do not open fully and they get twisted. Black spots on a green boll may often be indicative of pink bollworm damage. Affected bolls either open prematurely or get badly affected due to rotting by bacterial infection that results in the blackening of boll rind on the outside. Further the cotton lint in the insect infested bolls gets damaged by secondary fungal infection. Fiber qualities such as length and strength are also lowered. The seed cotton carried to market yards acts as a source for the pest to spread. Regular field surveys, pest monitoring and resistance monitoring studies should be carried out under insect resistance management program. The simplest and most potent way to overcome the problem is to take up timely sowing and cultivate of early maturing short duration varieties of about 150 days duration. All other management strategies such as avoidance of excess urea plus organophosphate insecticides, use of light traps, pheromone traps, biopesticides, biological control etc., have demonstrated encouraging results to minimize the damage to zero levels.

References

[1] Ahmad, M. and Khan, M.R. 1991. Insecticide resistance management strategies in cotton pests in Pakistan. Pak. Entomol., 13 (1-2): 1-4.

[2] Ahmad, N. and Sarwar, M. 2013. The Cotton Bollworms: Their Survey, Detection and Management through Pheromones: A Review. Journal of Agriculture and Allied Sciences, 2 (3): 5-8.

[3] Ahmad, N., Sarwar, M., Wagan, M. S., Muhammad, R. and Tofique, M. 2011. Conservation of bio-control agents in cotton, *Gossypium hirsutum* L. Field by food supplements for insect pests management. The Nucleus, 48 (3): 255-260.

[4] Arshad, M., Zain-ul-Abdin, Gogi, M.D. Arif, M.J. and Khan, R.R. 2015. Seasonal Pattern of Infestation by Spotted Bollworm, *Earias insulana* (Boisd.) and Pink Bollworm, *Pectinophora gossypiella* (Saund.) in Field Plots of Transgenic Bt and non-Bt Cottons. Pakistan J. Zool., 47 (1): 177-186.

[5] Bagla, P. 2010. Hardy Cotton-Munching Pests Are Latest Blow to GM Crops. Science, 327 (5972): 1439-1439.

[6] Beasley, C.A. and Adams, C.J. 1995. Effects of irrigation, irrigation timing, and cotton boll burial on extent and patterns of pink bollworm spring emergence. Southwestern Entomologist, 20 (1): 73-106

[7] Bellows, T. S. and Fisher, T. W. 1999. Handbook of Biological Control: Principles and Applications. Academic Press, San Diego, New York. 1046 p.

[8] Boguslawski, C.V. and Basedow, T. 2001. Studies in cotton fields in Egypt on the effects of pheromone mating disruption on *Pectinophora gossypiella* (Saund.) (Lep., Gelechiidae), on the occurrence of other arthropods, and on yields. Journal of Applied Entomology, 125 (6): 327-331.

[9] Busoli, A.C. 1993. Control of *Pectinophora gossypiella* (Saunders) and *Heliothis* spp. in cotton crop, using pheromones and by the mating disruption method. Anais da Sociedade Entomologica do Brasil, 22 (1): 139-148.

[10] Chaudhari, G.B., Bharpoda, T.M.,Patel, J.J.,Patel, K. and Patel, J.R.1999. Effect of weatheron activity of cotton bollworms in middle Gujrat. J. Agro. Meteor., 1 (2): 137-138.

[11] Ellsworth, P., Moore, L., Allen,C. Beasley, B., Henneberry, T. and Carter, F. 2006. Pink Bollworm Management. Newsletter of the Pink Bollworm Action Committee: A Project of the Cotton Foundation Produced by the University of Arizona - Cooperative Extension. 1 (2): 2.

[12] Ferre, J. and Rie, J.V. 2002. Biochemistry and genetics of insect resistance to *Bacillus thuringiensis.* Annu. Rev. Entomol., 47: 501-533.

[13] Gao, Z.R., Zhao, H.Y. and Jiang, Y.F. 1992. A study on the occurrence, damage and control of the pink bollworm in Henan Province. Plant Protection, 18 (4): 29-30.

[14] Gergis, M.F., Moftah, E.A., Soliman, M.A. and Khidr, A.A. 1990. Temperature-dependant development and functional responses of pink bollworm *Pectinophora gossypiella* (Saund.). Assiut Journal of Agricultural Sciences, 21 (3): 119-128.

[15] Gouge, D.H., Lee, L.L. and Henneberry, T.J. 1999. Parasitism of diapausing pink bollworm *Pectinophora gossypiella* (Lepidoptera: Gelechiidae) larvae by entomo pathogenic nematodes (Nematoda: Steinernematidae, Heterorhabditidae). Crop Protection, 18 (8): 531-537.

[16] Henneberry, T.J., Forlow, J.L. and Burke, R.A. 1996. Pink bollworm adult and larval susceptibility to steinernematid nematodes and nematode persistence in the soil laboratory and field tests in Arizona. Southwestern Entomologist, 21 (4): 357-368.

[17] Howse, P.E., Jones, O.T. and Stevens, I.D.R. 1998. Insect pheromones and their use in pest management. Ed. London: Chapman & Hall. 369 p.

[18] Jaleel, W., Saeed, S., Naqqash, M. N. and Zaka, S.M. 2014. Survey of Bt. cotton in Punjab Pakistan related to the knowledge, perception and practices of farmers regarding insect pests. International Journal of Agriculture and Crop Sciences, 14(7): 10-20.

[19] Jha, R. C. and Bisen, R. S. 1994. Effect of climatic factors on the seasonal incidence of thepink bollworm on cotton crop. Annuals of plant protection Science, 2:12-14.

[20] Kabissa, J.C.B. 1990. Seasonal occurrence and damage by *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechiidae) to cotton in eastern Tanzania. Tropical Pest Management, 36(4):356-358.

[21] Karsholt, O. and Razowski, J. 1996. The Lepidoptera of Europe: a distributional checklist. Stenstrup, Denmark: Apollo Books. 380 pp.

[22] Khalid, P.A., Hussain, M., Hassan, M., Sarwar, M. and Sarwar, N. 2015. Evaluation of Bt-cotton Genotypes for Resistance to Cotton Leaf Curl Disease under High Inoculum Pressure in the Field and Using Graft Inoculation in Glasshouse. The Plant Pathology Journal, 31 (2): 132-139.

[23] Khanzada, M.S., Syed, T.S., Khanzada, S.R., Abro, G.H., Salman, M., Anwar, S., Sarwar, M., Perzada, A.A., Wang, S. and Abro, A.H. 2016. Occurrence and abundance of thrips, whitefly and their natural enemy, *Geocoris* Spp. on cotton crop at various localities of Sindh, Pakistan. Journal of Entomology and Zoology Studies, 4 (1): 509-515.

[24] Khidr, A.A., Kostandy, S.N., Abbas, M.G., El-Kordy, M.W. and El-Gougary, O.A. 1990. Host plants, other than cotton, for the pink boll worm *Pectinophora gossypiella* and the spiny bollworm *Earias insulana*. Agricultural Research Review, 68 (1):135- 139.

[25] Mabbett, T. 1991. Pink bollworm management with pheromones. International Pest Control, 33 (3): 59.

[26] Mallah, G. H., Soomro, A. R.; Soomro, A. W.; Kourejo, A. K. and Kalhoro, A. D. 2000. Studies on the leftover standing cotton as carry-over sources of pink bollworm in Sindh. Pak. J. Bio. Sci.,3 (1): 147-149.

[27] Moar, W. J., Trumble, J. T.,Hice, R. H. and Backman, P. A. 1994. Insecticidal activity of the CryIIA protein from the NRD-12 isolate of *Bacillus thuringiensis* subsp. *kurstaki* expressed in *Escherichia coli* and *Bacillus thuringiensis* and in

a leaf-colonizing strain of *Bacillus cereus*. Appl. Environ. Microbiol., 60: 896-902.

[28] Parmar, V. R. and Patel, C. C. 2016. Pink Bollworm: A Notorious Pest of Cotton: A Review. AGRES - An International e-Journal, 5 (2): 88-97.

[29] Perlak, F.J., Oppenhuizen, M., Gustafson, K., Voth, R., Sivasupramaniam, S., Heering, D., Carey, B., Ihrig, R.A. and Roberts, J.K. 2001. Development and commercial use of Bollgard cotton in the USA - early promises versus today's reality. Plant Journal, 27(6) : 489-501.

[30] Sandhya, R.B., Prasad, N.V.V.S.D., Arjuna, R.P. and Srinivasa, R.V. 2010. Seasonal progression and incidence of *Pectinophora gossypiella* (Saunders) on Cotton. Ann. Plant. Prot. Sci., 2 (18): 323-326.

[31] Sarwar, M. 2013 a. Management of Spider Mite *Tetranychus cinnabarinus* (Boisduval) (Tetranychidae) Infestation in Cotton by Releasing the Predatory Mite *Neoseiulus pseudolongispinosus* (Xin, Liang and Ke) (Phytoseiidae). Biological Control, 65 (1): 37-42.

[32] Sarwar, M. 2013 b. Comparing abundance of predacious and phytophagous mites (Acarina) in conjunction with resistance identification between Bt and non-Bt cotton cultivars. African Entomology, 21 (1): 108-118.

[33] Sarwar, M. 2016. Bollworms *Earias vittella* (Fabricius) and *Earias insulana* (Lepidoptera: Noctuidae) Impairment in Cotton and Integrated Crop Management. Scholars Journal of Research in Agriculture and Biology, 1 (1): 1-7.

[34] Sarwar, M. 2017. Characteristics of Armyworm *Spodoptera litura* (Fabricius) (Lepidoptera: Noctuidae) Occurrence and Control on Cotton. Scholars Journal of Research in Agriculture and Biology, 2 (1): 33-38.

[35] Sarwar, M. and Sattar, M. 2016. An Analysis of Comparative Efficacies of Various Insecticides on the Densities of Important Insect Pests and the Natural Enemies of Cotton, *Gossypium hirsutum* L. Pakistan Journal of Zoology, 48 (1): 131-136.

[36] Sarwar, M., Hamed, M., Yousaf,M. and Hussain, M. 2013. Identification of Resistance to Insect Pests Infestations in Cotton (*Gossypium hirsutum* L.) Varieties Evaluated in the Field Experiment. Journal of Scientific Research in Environmental Sciences, 1 (11): 317-323.

[37] Shah, M. Ali, N. Memon,N. and Baloch, A. A. 2011. Use of sex pheromones and light traps formonitoring the population of adult moths of cotton bollworms in Hyderabad, Sindh, Pakistan. Sarhad J. Agric., 27 (3): 435-442.

[38] Silvie, P. and Goze, E. 1991. Estimate of cotton production losses caused by pests in Chad. Cotonet Fibres Tropicales, 46 (1): 15-32.

[39] Simmons, A.L., Dennehy, T.J., Tabashnik, B.E., Antilla, L., Bartlett, A., Gouge, D. and Staten, R. 1998. Evaluation of B.t. cotton deployment strategies and efficacy against pink bollworm in Arizona. 1998. Proceedings Beltwide Cotton Conferences, San Diego, California, USA, 5-9 January 1998. 2: 1025-1030.

[40] Tabashnik, B.E., Patin, A.L., Dennehy, T.J., Liu, Y.B,, Miller, E. and Staten, R.T. 1999. Dispersal of pink bollworm (Lepidoptera: Gelechiidae) males in transgenic cotton that produces a *Bacillus thuringiensis* toxin. Journal of Economic Entomology, 92 (4): 772-780.

[41] Tabashnik, B.E., Timothy, J. D., Maria, A. S., Karen, L., Graham, P.H. William, J. M. and Yves, C. 2002. Control of Resistant Pink Bollworm (*Pectinophora gossypiella*) by Transgenic Cotton That Produces *Bacillus thuringiensis* Toxin Cry2Ab. Appl. Environ. Microbiol., 68 (8): 3790-3794.

[42] Tadas, P.L., Kene, H.K. and Deshmukh, SD. 1994. Efficacy of some newer insecticides against cotton bollworms. PKV Research Journal, 18 (1): 138-139.

[43] Walters, M., Staten, R.T. and Roberson, R.C. 1998. Pink bollworm integrated management technology under field trial conditions in the Imperial Valley, CA. In: Dugger P, Richter DA, eds., Proceedings, Beltwide Cotton Conferences. Memphis, Tennessee: National Cotton Council. p. 1282-1285.

[44] Zhang, B.C. 1994. Index of economically important Lepidoptera. Wallingford, UK: CAB International. 599 p.

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