Retaining Early Formed Squares Will Lay a Robust Foundation for Pink Bollworm Management in India

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The pink bollworm (*Pectinophora gossypiella*) (PBW) has emerged as a major menace in India in the past 10 years (Figure 1). The worm is now feeding on BG-II cotton bolls because it has developed high levels of resistance to *Bt*-cotton in India. Several strategies have been recommended for its management (Kranthi, 2015). While these strategies are important in reducing PBW damage, they can be made more effective when coupled with one main strategy of 'retaining early formed squares' This paper explains the science behind the recommendation. It describes a simple set of novel strategies to retain the first formed squares in high density planting, which not only helps to obtain high yields, but also helps the peak boll stages to escape the infestation peaks of the worm.

I would like to explain a little bit more as to why the strategy of retaining early formed squares can help the crop to escape pink bollworm damage.

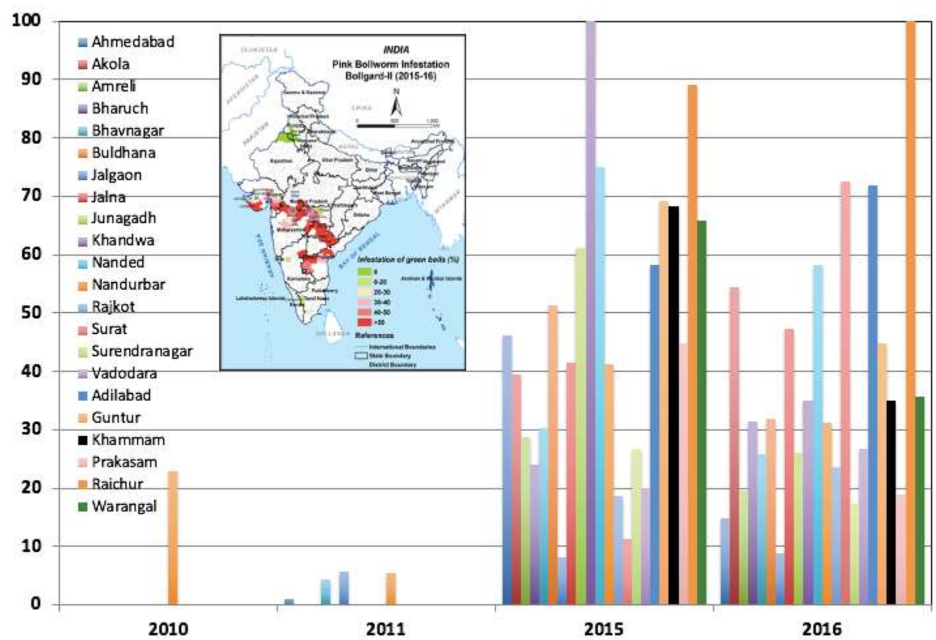

Figure 1. Recovery of PBW larvae from Bollgard-II *Bt* cotton in India

The strategy is based on the following four main scientific observations:

1. Research conducted by the ICAR-CICR and the AICRP clearly shows that the pink bollworm is a late season pest in India and late formed bolls are damaged mostly. In north India, the PBW populations appear in mid-September to assume a peak that generally occurs by mid-October; in central India PBW infests in November and peaks in early December; in south India the worms appear in December and reach peak levels by the beginning of January (Fand et al., 2021). Based on the recommended sowing months of April-May in north India; June-July in central India and July-August in south India, it can be surmised that in all the three zones, pink bollworm infestation on green bolls mainly starts after the plants attain 130 days of age. Green bolls formed within 130 days of the plant growth are generally safe from the pink bollworm. Data show that the worm occurs in 4-5 generation cycles in the cotton season starting with very low populations in the first generation that coincides with peak flowering stage, gradually leading to the third and fourth generations that cause maximum damage in late formed bolls.
2. PBW pestilence is high if the seasonal duration of preceding cotton crop was six to eight months or more. Cotton crops harvested within 150 to 160 days and terminated immediately, seldom get affected by the pink bollworm.
3. PBW neonate larvae prefer green bolls that are younger (Liu et al., 2002) that are 14 to 21 days old (Van Steenwyk et al., 1976; Henneberry and Clayton, 1982). Green bolls grow to their full size in 21 days after which they are generally considered to be relatively safer from fresh bollworm attack. It takes 45 to 50 days for a square bud to reach the stage of a full-size safe green boll. Tender green bolls are most vulnerable to fresh bollworm infestation when they are one to three weeks old.
4. In general, a 40 days old plant starts producing square buds. On average one square bud is produced per day: the production rate being dependent on genetics and environment. Presuming that all squares are retained, and no squares are shed, a plant at 130-days of age is expected to produce about 40 full-sized green bolls that are safe from fresh infestation by PBW. The plant could also have about 10-15 younger green bolls and will produce more squares/flowers and younger bolls subsequently that are most likely to get caught in PBW infestation.

Square and boll shedding are common phenomena in cotton fields across the globe. It is generally accepted that despite best management practices it may be possible to retain about 50% healthy open bolls from the squares produced by a plant, after 30% square shedding and 30% shedding or damage of the bolls that are formed out of the remaining squares. Therefore a 130-days old plant may have at best about 20 retained full-sized bolls that are safe from fresh PBW attacks and 8-10 younger green bolls that will be vulnerable to PBW infestation. Because PBW is a cryptic (hidden) pest, the crop, which is vulnerable to PBW after 130 days, can only be partly protected from PBW damage by resorting to integrated pest management strategies that include pheromone mass trapping using the traps and prolonged-effect lures developed by ICAR-CICR. The lures can also be used for mating confusion. Whenever necessary, insecticides such as ememectin benzoate, flubendiamide, chlorantraniliprole or spinosad or indoxacarb or novaluron or thiodicarb (http://www.aiccip.cicr.org.in; Divya *et. al*., 2020) can be used at economic threshold levels of 8 moths per trap per night for three consecutive nights.

Figure 2. Pink bollworm larval damage

Figure 3. Pink bollworm damaged rosette flowers

Figure 4. Pink bollworm pupa

Figure 5. Pink bollworm moth

Table 1. Predicted Crop Phenological Stages in Central India

Date	Age of the crop	Phenological stage
15-Jun		Sowing
20-Jun	0	Seedling emergence
30-Jul	40 days old	Square formation starts
10-Sep	80 days old	40 squares are produced per plant
05-Oct	105 days old	40th square blooms into a flower
30-Oct	130 days old	40th square produced by the plant will have turned into a full-size green boll that is safe from a fresh bollworm attack. The chances are that from the 40 squares produced, only 20 green bolls or less will be retained per plant.
01-Nov	131 days old	Pink bollworm starts attacking tender green bolls (<20 days old). Green bolls produced after mid-October are tender and vulnerable to a fresh attack by the pink bollworm in November and later.
01-Dec	161 days old	PBW populations reach a peak and cause significant damage

Data shows that in central India, pink bollworm infestation starts in November and reaches a peak by late November to early December. Green bolls that reach full-size by the end of October escape the pink bollworm and green bolls that are formed later, which are less than 20 days old are vulnerable to PBW oviposition and infestation. Green bolls formed before the end of October are also likely to receive the benefit of residual soil moisture and available nutrients depending on moisture retention capacity of the soil and the seasonal rainfall pattern. Under a normal monsoon pattern, most soils in rainfed farms become dry by the end of October and late formed bolls suffer stress. Bolls harvested from the shorter season crop are healthier and produce clean good quality fibres, because they are rarely starved of water and nutrients and also because they escape PBW infestation.

Cotton plants compensate for square shedding. Shedding of early formed squares prompts plants to shift towards vegetative growth by producing new fruiting branches and new squares in efforts to compensate for the lost squares and bolls. However, compensation needs energy; it leads to elevated requirements of water and nutrients thereby accelerating stress; further loss of fruiting parts and a longer crop duration. A longer season leads to late formed bolls that are most vulnerable to PBW infestation, which in turn leads to a higher number of PBW generations and a need to extend the crop to recover lost yield. A longer season thus supports higher pestilence in the current and the subsequent cotton crop.

Research clearly confirms that 'retaining early formed squares' enables higher 'water-use-efficiency', better 'nutrient-use-efficiency' and efficient energy partitioning without subjecting plants to any additional stress. Further, higher yields can be obtained from a timely sown, shorter season crop of 150 to 160 days by combining the strategy of 'retaining early formed squares' with high density planting (see explanation below).

Technologies that help to retain early formed squares and bolls may optimally enable a retention of 50% healthy bolls from the total number of squares produced and at worst enable 30% retention. Data indicates that low yields in India and Africa are mainly due to low density of plant population coupled with higher rate of square/boll shedding/damage which could reach as high as 80 per cent or even more.

How can high yields be obtained from a short season crop of 150 to 160 days?

High yields can be obtained from any crop irrespective of the level of plant population density, by preventing shedding of early formed squares and bolls to the best extent possible. However, to obtain the same level of yield, a crop with low density plant population will require a longer duration, while a crop with a higher density plant population will require a shorter duration depending on the density levels. I am presenting two tables below to explain how plant population density influences the crop duration to harvest the same level of yield and how high yields can be obtained from a short season crop of 150 to 160 days.

Table 2. Yields (Kg/ha) from a short season crop of 150 to 160 days at different plant densities

Plant spacing (90 cm between rows)	Plant population per hectare	Number of healthy bolls retained per plant on 130 days old plants, that escape PBW infestation	*Calculated lint yield Kg/ha @ 20 healthy bolls retained per plant on 150 to 160 days old crop
90 x 90cm	12,345	20	247
90 x 60cm	18,518	20	370
90 x 45cm	24,691	20	494
90 x 30cm	37,037	20	741
90 x 15cm	74,074	20	1481
90 x 10cm	111,111	20	2222

*The average lint weight in Indian bolls is about 1.3g. For calculation purposes of a worst-case scenario, each open boll was assigned a value of 1.0g lint.

Table 2 shows a hypothetical case as an example where technologies are used to ensure retention of 20 healthy full-formed bolls from 40 squares formed on a 130-days old plant by retaining 70% of the first formed squares and 70% bolls that resulted from the retained squares. At a low plant density of 12,345 plants per hectare, with each boll providing 1g lint, the calculated yield is 247 Kg lint per hectare from a 150-160 days old crop. In stark contrast, the calculated yield would be 2,222 Kg lint per hectare from the same duration of 150-160 days old crop at a plant population density of 111,111 plants per hectare.

Table 3. Number of retained healthy bolls required to get 778 kg lint/ha (2018 world average) and calculated crop duration for the target yield at different plant densities

Plant spacing (90 cm between rows)	Plant population per hectare	Number of healthy bolls (@ 50% retention), required to get 778 kg lint/ha	Calculated crop duration (days) to get 778 kg lint/ha at 50% boll retention
90 x 90cm	12,345	62	247
90 x 60cm	18,518	42	205
90 x 45cm	24,691	31	184
90 x 30cm	37,037	21	162
90 x 15cm	74,074	10	141
90 x 10cm	111,111	7	134

Table 3 estimates the number of bolls and the duration of the crop required to achieve a target of the world average lint yield of 778 Kg/ha., at different plant densities. The table highlights the need for a longer duration of 247 days and a higher number of 62 healthy bolls at 50% retention rate at a low plant population density of 12,345 plants per hectare to harvest a target lint yield of 778 Kg/ha, in stark contrast to high density planting system of 111,111 plants per hectare which needs only 7 bolls per plant and just 134 days to achieve the same target yield of 778 Kg/ha. Thus, fields with low density of plant populations require retention of a greater number of squares per plant to obtain the same target yield. Retention of a greater number of squares and bolls per plant means a longer seasonal window for similar yields that can also be obtained from a shorter season with higher density of plants per hectare.

A long duration crop is not desirable from a management perspective because it mandates a long vulnerable management window. A longer window of flowering and tender green bolls imposes higher challenges for a longer vigilance-window to provide adequate water, nutrients and protect the crop against bollworms. For example, to retain 127 squares for 62 bolls per plant at 49-50% retention, it would require a vigilant management window of up to 177 days to minimize shedding, starting from the square initiation stage until ensuring the safety of the last batch of bolls. On the other hand, retaining 14 squares for 7 bolls per plant would require an initial vigilant management window of only 64 days to minimize shedding starting from the square initiation stage until ensuring the safety of the last batch of bolls. A longer season is a recipe for disaster in terms of crop management and bollworm management, especially because it necessitates higher use of water, fertilizers and pesticides apart from creating a perennial cyclic problem of the pink bollworm.

Retaining early formed squares and bolls

Squares are formed sequentially on the fruiting branch, first at the first position node (see figure 1 below), followed by the next square on the second position approximately after six days (depending on genetics and environment) and so on. (Figure 6)

The first position square/bolls are most favoured by the plant for nutrition and water, followed by the second and third position fruiting parts. Data show that the first and second position bolls have the best quality fibre because they receive a preferential treatment. Shedding of these fruiting parts imposes high levels of stress to the plant. Research across the world showed that bolls at the first, second and third position of the fruiting branches contribute most towards harvestable yields at about 60%, 30% and 10% respectively. Therefore, retention of at least the first and second position squares/bolls, which represent the early formed fruiting parts, is crucial for high yields.

Figure 6. Position of fruiting parts on a fruiting branch

Minimizing shedding of early formed squares/bolls results in higher production efficiency of plants, synchronous early maturity, escape of damage by pink bollworms, high yields in a short season and facilitates timely termination of the crop.

Formation of fruiting parts depends on ideal conditions of heat, light, water, nutrients and absence of biotic and abiotic stress. Early formed squares are shed mainly due to one or more of three major factors:

- Canopy-shading or cloudy conditions or waterlogging or drought or extreme temperatures
- Deficiency of nitrogen or phosphorus or boron
- Insects such as plant bugs, mirid bugs or bollworms
- Square shedding can be effectively minimized by using any of the following technologies

Chemical sprays to interfere with abscission

A number of chemicals that interfere with abscisic acid and ethylene levels in the plant have been used as foliar sprays early in the season to minimise physiological square shedding. For example, spray of 1-Naphthalene Acetic Acid (NAA) @ 40ppm during early square formation stage has been found to minimize physiological square shedding. Ethylene inhibitors such as Aminoethoxy Vinyl Glycine (AVG) and 1-Methyl Cycloprene (MCP) have also been found to minimize physiological shedding of squares and bolls (Brito et al., 2013; Najeeb et al., 2015). Several other chemicals such as Amino-oxy-acetic acid (AOA), Triacontanol, 2,3,5-Tri-Iodo-Benzoic Acid (TIBA), Silver thiosulphate, Silver nitrate and Trans-cyclo-octene have been tested across the world in cotton for their role in inhibiting square and boll shedding (Patel, 1993; Freytag and Coleman, 1973; Prakash et al., 2007; Tariq et al., 2017). There is a need to validate their dose and application at proper growth stage under local conditions.

Canopy management

Mepiquat Chloride (15 to 30g a.i/ha) is commonly used in developed countries at 50-80 days after sowing at bi-weekly interval (Cook and Kennedy, 2000; Srivastava, 2002) for canopy management at thresholds of >4.0cm average internodal length of the main stem to prevent canopy-shading. Canopy management in the early stages of square formation is crucial for proper light penetration to reduce shedding of squares and early formed bolls. Alternatively, Paclobutrazol (40g a.i/ha) can also be used as one or two applications during 50 to 80 days for canopy management and to prevent square and boll shedding (Temiz et al., 2009; Choudhary and Choudhary, 2016).

Nutrient management

Application (basal dose or foliar sprays at early squaring stage) of nitrogen / phosphorus / boron based on soil fertility helps in minimizing square and boll shedding.

Boron application

Boron plays an important role in square and boll retention. A list of cotton growing districts where majority of farms were reported to be boron deficient, is presented below (Table 4). Boron must be applied in fields where it is reported to be deficient. Depending on the deficiency, Borax must be applied as band placement at 10 to 20 Kg/ha at the time of planting and if necessary, as foliar sprays of 0.1 to 0.3% on 40-80 days old crop to minimize square shedding.

Soil Moisture management

Draining of waterlogged fields and providing irrigation as and when required by the plants helps in minimizing square shedding.

Insect pest management

Plant bugs, mirid bugs and bollworms cause square shedding. Bugs can be controlled using selective insecticides such as

Table 4. Districts where boron deficiency has been recorded in majority of the farms tested

Maharashtra	Jalna, Nagpur, Nanded and Satara
Punjab	Bhatinda and Patiala
Karnataka	Bagalkot, Belgaum, Bellary, Bidar, Bijapur, Chikballapur, Chikmagalur, Gulbarga, Hassan, Haveri, Koppal, Mysore, Tumkur and Uttar kannada.
Madhya Pradesh	Betul, Dhar and Neemuch
Tamilnadu	Coimbatore, Cuddalore, Dindigul, Erode, Madurai, Namakkal, Sivaganga, Tiruchirappalli, Tirunelveli, Tiruvannamalai, Tuticorin, Villupuram and Virudhunagar
Telangana	Nagarkurnool and Rangareddy
Haryana	Sirsa
Odisha	Anugul, Balangir, Boudh, Ganjam, Kalahandi, Kandhamal, Kendujhar, Koraput, Nabarangpur, Nayagarh, Nuapada and Sonepur
Gujarat & AP	No data

Azadirachtin-based insecticides or Diafenthiuron or Buprofezin or Flonicamid. Early season bollworm infestation can be efficiently controlled with biological control or Indoxacarb or Chlorantraniliprole or Spinosad or Flubendiamide or Emamectin benzoate at doses and ETLs recommended by ICAR-CICR (http://www.aiccip.cicr.org.in). These insecticides are relatively selective with higher toxicity to target pests and lesser toxicity to beneficial insects. (Table 4)

Other strategies of PBW management and high yields from a short season

Basically, all cotton varieties across the world are indeterminate which means genetically ordained to produce bolls continuously for multiple picking. A combination of genetics, agronomy and physiological techniques is used to orient the crop towards single picking. It is with these technologies that countries such as Australia, China, Brazil, Turkey, Mexico and USA are able to harvest high yields of 1000 to 2000 Kg lint per hectare in a short season of 5-6 months compared to the average Indian yield of 500 Kg/ha in 7-8 months. High yields of 1000 to 2000 Kg/ha are obtained in Brazil, Australia, Mexico, Greece, Spain and USA through single picking and in China through multiple picking. These countries use high density planting coupled with canopy management and protection of early formed squares so that the crop duration is kept short (5-6 months) and high yields can be harvested within a single synchronous picking. Brazil is almost completely rainfed and USA cotton is 35% irrigated just like India. Indian weather is actually best suited for cotton compared to these countries. However, Indian average yields are only as good as a few resource-poor rainfed Africas countries such as Cameroon, Cote D'ivoire, Benin and Mail, which nether have *Bt* nor Hybrid cotton and use less than one-fifth of the fertilizers that India uses.

Following is a list of five main strategies that are critical for India to harvest high yields and move towards a robust long term PBW management system.

1. **Area-wide cotton-free closed season of 6 months**

   While it is important that India explores options of short season cotton (5-6 months) and enables an area-wide cotton-free 'closed season' of 6 months, four other strategies also play a critical role in PBW management. Pink bollworm feeds mainly on cotton and a six months cotton-free period hits it very hard. Timely termination of the crop within 5-6 months helps the crop to escape PBW which is primarily a late season pest that starts its main infestation after mid-November. A closed season significantly reduces pest carry over to the next season. Though timely termination and closed season play an important role in minimizing pest carry over of normal PBW populations that will not survive in the absence of food, the presence of diapausing larvae that are dormant during the cotton-crop-free period, presents a serious challenge.

2. **Destruction of unharvested boll and gin waste**

   Some of the PBW larvae enter diapause at end of the season. These larvae pupate and moths emerge in the subsequent season when the crop starts flowering. Most of the diapausing larvae take shelter in unharvested immature bolls and also inside seeds. Very few diapausing larvae drop on the soil. Therefore, the second most important strategy is to destroy all residual unharvested bolls and also destroy gin waste which contains diapausing larvae.

3. **Retention of early formed squares**

   Retain early formed squares (flower-buds) through canopy management, controlling mirid bugs, application of Boron sprays wherever deficiency is prevalent and naphthalene acetic acid (NAA) sprays to combat physiological stress. More than 60-70% of early formed squares are shed in India and the crop stretches itself into a long season in its attempts to compensate the early losses.

4. **Early season mass trapping and mating confusion**

   Use mass trapping and mating confusion techniques during early flowering stage so that the first generation PBW moths are least productive. A new slow-release pheromone formulation was developed (Kranthi, unpublished) and commercialised as a mass trap that attracts and traps male moths for 50 to 60 days without the need to change lures. The pheromone lures and traps can be procured from Innovative Biosciences Nagpur or Central Institute for Cotton Research Nagpur. Studies showed that 50 traps per hectare were effective is mass trapping moths in the early stages of the crop to reduce subsequent pestilence. Mating confusion technique requires at least 500 PBW pheromone ropes or dispense spots. For small holder farming conditions, mass trapping could be a better option compared to mating confusion not only because it is much inexpensive, but also because it is possible that the moths from pheromone treated plots are likely to disperse into neighbouring pheromone-untreated fields.

5. **Pheromone monitoring and control**

   Pheromone traps offer an elegant option for PBW monitoring. Control measures can be initiated at an economic threshold levels (ETLs) of eight moths per trap per night for three consequent nights, with eco-friendly insecticides, biopesticides and biological control. The following interventions, namely application of azadirachtin or *Trichogramma bactrae* or chlorantraniliprole, spinosad, flubendiamide, emamectin benzoate, indoxacarb etc., were found to be effective and relatively less toxic to naturally occurring biological control compared to conventional insecticides belonging to the classes of organophosphates and synthetic pyrethroids.

These five strategies have the potential to lay a firm foundation for PBW control.

The feasibility of adopting 'mating confusion', 'sterile insect release techniques (SIT)' 'refuge-in-bag' 'new *Bt* genes' and 'short season' strategies for PBW management in India and Pakistan

An intensive discussion has been taking place in India and Pakistan to explore the best options for long term management of PBW. At least strategies, namely 'mating confusion', 'sterile insect release techniques' 'refuge-in-bag' 'short season' and novel genes based *Bt*-cotton are discussed most frequently.

Mating confusion and SIT

Sterile insect release technique and pheromone-based mating confusion techniques together are believed to have contributed immensely in PBW eradication in USA and Mexico. Both these techniques require area-wide implementation and are very expensive. The release of billions of male sterile moths has to be essentially driven by a Government policy that is approved by farmers. The mass production of sterile moths and regular aerial releases are extremely expensive and appear to be improbability in India and Pakistan. Pheromone based mating confusion requires at least two releases of 500 PBW pheromone ropes per hectare or 2-3 applications of Specialized Pheromone & Lure Application Technology (SPLAT) are expensive and appear to beyond the reach of small holder farmers. Further, there are very few studies that better our understanding as to whether the confused male moths remain in the pheromone-treated field or disperse to the neighbouring pheromone-untreated fields in search of females to create more pestilence.

Refuge-in-bag

A non-*Bt* cotton refuge has the potential to delay resistance when it has not surfaced or when it is at a low level. However, refuges will not be able to reverse PBW resistance to *Bt*-cotton or minimize pest damage. The Government of India in an official gazette notification (December 2016) stipulated that the *Bt* seeds in a 'refuge-in-bag' should be between 90 to 95% and the isogenic non-*Bt* refuge cotton seeds of the corresponding *Bt*-hybrids must be between 5 to 10%. Under the given conditions, the 'refuge-in-bag' strategy will not make any tangible difference to the prevalent 'PBW resistance to *Bt*-cotton' nor will it be able to strengthen PBW management in any manner.

New Bt-gene transgenic cotton

Tabashnik (2021) suggests the use of *Bt* genes Cry1B and Cry1C for new transgenic cotton. It remains to be seen if PBW which is a functionally monophagous pest will remain susceptible for long to the new transgenes, Cry1B and Cry1B if the ecological conditions of long season cotton continue to be the same as they are today.

Area-wide short season and closed season

A short season is critical for an area-wide closed season. Indian farmers and seed companies generally believe that high yields are possible only with a long season. Harvesting high yields with short season is in many countries has been possible only with high density planting (90x10cm) provided the early formed squares are retained at least to 70-80%. Hybrid cotton is not very conducive for high density planting because of the costly seeds. Therefore pure-line varieties are a better option as is the case in the countries that harvest more than 1000 Kg lint per hectare. Turkey, Greece and Spain grow non-*Bt* varieties and harvest 1000 to 1700 Kg lint per hectare with 3-6 applications of insecticides. There is no reason to believe that this will not be possible in India and Pakistan.

The short season high density cotton presents advantages and disadvantages. There are at least three advantages. The HDPS single pick system enables to obtain high yields within a short time, because the green boll formation window which is most critical for pest and nutrient management is short (40-50 days), compared to the longer window (40-120 days) as is the case now in India. Fibre quality of early picked synchronous bolls is relatively uniform and much better than the late picked bolls. Short season cotton if grown in an area-wide manner to ensure an area-wide closed season of 5-6 months will certainly bring down PBW populations significantly. The disadvantages could be mainly due to drought and the difficulty of criss-cross hoeing for weed management, which is the main method of weed control in India. Drought poses the biggest threat to short season systems which in some cases may not provide congenial conditions for the crop to compensate a severe damage. Management in cropping systems designed for a short season becomes critical if the crop gets damaged in the early stages due to drought effects, flooding or insect infestation. Weed management between plants will need extra attention because criss-cross hoeing is not possible in high density systems because of the narrow 8-10 cm spacing between plants. Studies (Kranthi, unpublished) showed that weeds can be managed with hoeing between rows and if necessary, with application of any selective herbicide between plants.

Conclusion

The pink bollworm is a monophagous pest with cotton as the primary host. A 'closed season', where no cotton or PBW alternate host crops are allowed to be grown between two cotton seasons, is almost universally enforced, wherever cotton is cultivated to prevent carry over of PBW from the previous crop. Currently strict adherence to this 'closed season' is one of the most effective methods available for the control of pink bollworm in Africa and a key IPM strategy across the world. Deployment of 'short season' and 'closed season' are the most common universally recommended strategies for PBW management. These two strategies along with high density planting were used to produce high yields and effectively combat the serious menace of PBW in the desert valleys of southern California and Arizona in the mid-1970s to the mid-1980s; and would be most applicable to combat the current PBW crisis in India. Pink bollworm is known to cause least problems in countries that cultivate short-season cultivars and implement a closed-season of at least 5 to 6 months. Therefore, the best strategies for PBW management in India would be to ensure timely sowing in an area-wide manner and retention of early formed squares in high density planting so that high yields can be obtained from a short season crop; destroy unharvested bolls and seeds harbouring diapausing larvae; monitor and manage the first 1-2 generations of PBW through mass trapping and eco-friendly insecticides and timely termination of the crop.


Photograph: Mahesh Upender

References

Brito, G.G.D., Ferreira, A.C.D.B., Borin, A.L.D.C. and Morello, C.D.L., 2013. 1-Methylcyclopropene and Aminoethoxyvinylglycine effects on yield components of field-grown cotton. *Ciência e Agrotecnologia*, *37*(1), pp.9-16.

Choudhary, R.S. and Choudhary, R., 2016. Paclobutrazol Enhances Seed Cotton Yield by Restricting Vegetative Growth and Shedding of Squares/bolls in Cotton (Gossypium spp.). *International Journal of Bio-resource and Stress Management*, *7*(3), pp.369-372.

Cook, D. R., Kennedy, C. W. 2000. Early flower bud loss and mepiquat chloride effects on cotton yield distribution. Crop Science, 40(6):1678- 1684. DOI: 10.2135/cropsci2000.4061678

Divya, B., Navi, S., Sugeetha, G., Vijaykumar, L., Kumar, S., Somu, G. and Patel, V.N., 2020. Evaluation of newer molecules for the management of pink bollworm, *Pectinophora gossypiella* (Saunders)(Lepidoptera: Gelechiidae) in cotton (Gossypium spp.).

Fand, B.B., Nagrare, V.S., Bal, S.K., Naik, V.C.B., Naikwadi, B.V., Mahule, D.J., Gokte-Narkhedkar, N. and Waghmare, V.N., 2021. Degree day-based model predicts pink bollworm phenology across geographical locations of subtropics and semi-arid tropics of India. *Scientific Reports*, *11*(1), pp.1-18.

Freytag, A. H., Coleman, E. A. 1973. Effect of multiple applications of 2, 3, 5- triiodobenzoic acid (TIBA) on yields of stormproof and non-storm proof cotton. Agronomy Journal, 65(4):610-612.

Henneberry, T.J. and Clayton, T.E., 1982. Pink bollworm: seasonal oviposition, egg predation, and square and boll infestations in relation to cotton plant development. *Environmental Entomology*, *11*(3), pp.663-666.

Liu, Y.B., Tabashnik, B.E., Dennehy, T.J., Carrière, Y., Sims, M.A. and Meyer, S.K., 2002. Oviposition on and mining in bolls of *Bt* and non-*Bt* cotton by resistant and susceptible pink bollworm (Lepidoptera: Gelechiidae). *Journal of Economic Entomology*, *95*(1), pp.143-148.

Najeeb, U., Atwell, B.J., Bange, M.P. and Tan, D.K., 2015. Aminoethoxyvinylglycine (AVG) ameliorates waterlogging-induced damage in cotton by inhibiting ethylene synthesis and sustaining photosynthetic capacity. *Plant Growth Regulation*, *76*(1), pp.83-98.

Patel, J. K. 1993. Response of rainfed upland cotton to triacontanol and naphthalene acetic acid sprays. Indian Journal of Agronomy, 38(1):97-101.

Prakash, A. H., Gopalakrishnan, N., Khader, S.E.S.A. 2007. Model Training Course on "Cultivation of long staple cotton (ELS), Central Institute for Cotton Research, Regional Station, Coimbatore, December 15- 22, p: 201-206

Srivastava, L. M. 2002. Gibberellins. In: Srivastava, L.M. Plant Growth and Development. Academic Press, New York, NY, USA. Pp. 172–181.

Tabashnik. 2021. India must return to IPM and explore new *Bt* genes. The ICAC RECORDER. March 2021.

Tariq, M., Yasmeen, A., Ahmad, S., Hussain, N., Afzal, M.N. and Hasanuzzaman, M., 2017. Shedding of fruiting structures in cotton: factors, compensation and prevention. *Tropical and Subtropical Agroecosystems*, *20*(2), pp.251-262.

Temız, M., Cımen, I. and Karahan, E., 2009. Effect of paclobutrazol on fiber quality of cotton (Gossypium hirsutum L.). *Asian Journal of Chemistry*, *21*(3), pp.1990-1994.

Van Steenwyk, R.A., Ballmer, G.R. and Reynolds, H.T., 1976. Relationship of cotton boll age, size and moisture content to pink bollworm attack. *Journal of Economic Entomology*, *69*(5), pp.579-582.