COMMENTARY

An area-wide approach to pink bollworm management on *Bt* cotton in India – a dire necessity with community participation

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Unusually high levels of pink bollworm (PBW) infestation and crop damage were experienced in the fields of the dual *Bt*-gene cotton (Bollgard II®) technology, a genetically modified cotton which produces two *Bt* insecticides (Cry1Ac and Cry2Ab) to combat cotton bollworms, in Gujarat, Madhya Pradesh, Maharashtra, Karnataka and Andhra Pradesh during *kharif* season of 2015 (refs 1, 2), and in the early part of the 2016 season in Saurashtra, Gujarat[3] and Haveri, Karnataka[4]. These incidences caused great concerns in the cotton trade chain because of the impact on cotton output and reduced market price of PBW-damaged cotton, and equally among the scientific fraternity because it indicated that PBW, which had been well managed by *Bt* traits in cotton in the past, was now capable of feeding on Bollgard II crop. A study by the Central Institute for Cotton Research had indicated that the unusual damage by PBW to Bollgard II in 2015 could be due to resistance evolution by the insect to the dual *Bt*-gene cotton[1], which had provided excellent protection against all bollworms since its introduction in 2006. Field-resistance to the single *Bt*-gene cotton (Cry1Ac) in PBW populations from Gujarat was reported in 2010 (ref. 5).

Clearly, PBW has been developing resistance to the *Bt* genes over time and these events also bring into sharp focus the subject of responsible use of *Bt* cotton technology. More specifically, Indian cotton farmers have not been planting the prescribed 'refuge' area with non-*Bt* cotton. Secondly, farmers have been ignoring PBW-specific pest management practices like cultivation of early/medium maturing cotton hybrids and strict avoidance of rejuvenation/reflush after harvest, especially in PBW endemic areas; summer ploughing to destroy hibernating PBW larvae and pupae; destruction of unopened bolls on stalks and in the soil; regular scouting of flowers and bolls and/or pheromone traps to decide on insecticide sprays, and avoid storing of PBW-damaged cotton in homes. These time-tested pest-management practices collectively suppress PBW population in cotton fields, manage *Bt* resistance development and promote long-term sustenance of *Bt* cotton technology.

Among the cotton bollworms, PBW has been the most enigmatic in the context of *Bt* cotton because of its biology. PBW is known to feed and multiply only on conventional non-GM cotton (non-*Bt*). Considering that *Bt* cotton covered >95% of total cotton acreage (~11 million ha) in 2015, PBW has evidently come under increasing selection pressure to evolve resistance to *Bt* protein(s) produced in tissues of *Bt* cotton plants. Secondly, even as an alternative control method, conventional insecticides have limited efficacy on PBW due to the internal feeding habit of the larvae within the developing cotton boll.

It is here that the understanding generated by Indian scientists on the biology and ecology of PBW in the context of Indian cotton ecosystem has to be utilized to identify opportunities for intervention. PBW moths continuously emerge between April and August from the soil and plant debris of the previous season. PBW-infested and trashed seed heaps in cotton gins are another source. A large proportion of emergence becomes 'suicidal' or non-productive when there is no right stage of cotton crop in the field. Beginning from August, with the availability of cotton squares, flowers and bolls, the population gradually builds up to reach economically damaging level generally after 90 days of the crop. Typically, damage to non-*Bt* cotton bolls by PBW becomes visible between November and February when the pest completes at least three additional generations on cotton and the population rises exponentially. A large residual population close to harvest means large carryover to the next season. In certain irrigated tracts of Gujarat and the Narmada belt of Maharashtra, many farmers extend the cotton cropping beyond 140 days to 230 days through rejuvenation (termed 'reflush') of cotton plants. This is a practice unique in this part of the country and brings in additional seed cotton to the farmer; this practice is favoured especially if the main crop has been affected due to factors such as extremities of weather, pest attack or other disorders. Unfortunately, from a PBW management perspective, rejuvenation supports further increase in the PBW population by at least 2–3 generations. The carryover to the next seasons from such fields can be expected to be much larger. Here is a good opportunity for the farmer to break the pest cycle by not opting for extended cotton cultivation. Similarly, PBW gets extended time for further multiplication in cotton seed production areas in South India, where cotton is cultivated throughout the year. Rigorous scouting and need-based sprays can manage PBW in these areas. On their own PBW moths are not known to fly large distances, especially when cotton crop is available in the near vicinity for mating and egg-laying. However, strong monsoon wind movement can take the moths across long distances. Transport of cotton stalks with PBW-infested bolls after harvest for fuel purposes from infested to new areas also acts as a mode of spread of PBW.

Genetically modified *Bt* cotton (Bollgard®), introduced in 1996 in USA and 2002 in India, effectively managed PBW because the insecticidal *Bt* protein Cry1Ac, produced in cotton bolls was effective against PBW and other lepidopteran pests. Bollgard II®, approved in India in 2006, was also effective in managing PBW and was a better resistance management tool.

PBW populations found in many states during *kharif* 2015 and 2016 cannot be eliminated in one or two seasons. Using the knowledge on the biology and nature of spread of PBW in Indian cotton fields, a successful wide-area (for example, village) management strategy based on whole community participation needs to be adopted urgently, as opposed to field-by-field management, the usual norm in any insecticide application. An area-wide PBW suppression would essentially utilize the tactics of integrated pest management (IPM), the elements of which are well known and were practised in endemic areas of PBW during the pre-*Bt* era, but were abandoned by the farmers

with the introduction of *Bt* cotton. IPM measures are ecologically and economically viable with a reasonably high probability that the farmer would adopt them because of low cost and driven by the urge to save his crop from PBW. As a prelude, extension agencies of State Departments of Agriculture, agricultural universities, cotton research institutions, cotton seed producers and seed associations need to internalize the action plan first and facilitate a strategy for farmers and ginners involving community-wide approach for PBW management. A concerted effort among the agencies is a must and preferably driven top-down. Insecticidal applications are expected to play a key role in PBW population suppression, but equally important is the role of extension agencies for advisories on the choice of insecticide and timing of spray. Only registered insecticides should be allowed in the market with a strict vigil on spurious concoctions. As the first step, mapping of PBW incidence, in terms of severity (boll infestation levels), should be undertaken in the various districts from where incidence was reported in *kharif* 2015. This would help the extension field-teams to rationalize resources.

Cotton cultivation practices, specifically for managing PBW (outlined below) need to be revived and reinstated in the fields.

Pre-sowing: Deep summer ploughing; planting early maturing *Bt* cotton hybrids, especially in PBW 'hotspots'; planting only non-*Bt* cotton and not any other refuge crop because cotton is the only host for PBW.

In-season (bloom to harvest): Determining economic threshold levels (ETL) for spray decisions through PBW monitoring traps (5 traps/ha and ETL being 8 moths/trap/night for three successive nights), and larval infestation through flower inspection (ETL – 10% flowers with PBW larvae) and scouting in developing bolls (ETL – 10% bolls with larvae). ETL based insecticide applications are effective in suppressing infestation levels in flowers and bolls. PBW pheromone traps (20/ha) could be used for mass trapping adult males when PBW moth population in the crop-ecosystem exceeds the ETL by several folds.

Post-harvest (between harvest and new sowing): These are essentially practices to break the pest cycle like timely crop termination; destruction of unopened bolls and boll residues in field and cotton gin sanitation practices for PBW.

Affected states may also consider enacting legislations or notifications to provide teeth to wide-area management. For example, some of the regulatable measures could be inspection and destruction of PBW-damaged seeds in cotton gins; legislation enforced cut-off date for ginning and oil extraction which could be at least 45 days prior to sowing of new cotton crop; restriction on interstate movement of cotton seeds for oil extraction; strong awareness drive on the importance of planting short/medium duration cotton and deterrents on extending the cropping cycle through rejuvenation in PBW-endemic areas. Adjusting the sowing window, an accepted cultural practice for pest avoidance, may not be practical in all regions because of the heavy dependence on pre-monsoon showers, which have become unpredictable in recent times. In short, what is direly needed is a commitment and a goal on PBW eradication that will knit the Indian cotton community together for affirmative action.

Area-wide management of crop pests is not new and is based on the principle that moderate and persistent control pressure applied on a wide area will be more effective in suppressing an insect pest as opposed to intense control pressure applied to a small segment of the population. Effective application of this practice will depend on the biology of the insect pest being suppressed, but suffice to say that PBW in the Indian cotton ecosystem will be amenable to this control principle.

In the history of cotton cultivation in USA, PBW and boll weevil, endemic and serious pests in southwestern USA, could be successfully managed by adopting area-wide management and community participation, conceptualized and driven by the United States Department of Agriculture[6–8], and ably supported by legislative enforcement. Cotton cultivation has a long history in India and practices aimed at managing PBW have been well researched and established[9,10]. We should take advantage of these learnings.

Undoubtedly, *Bt* cotton technology has ushered in tangible benefits to the farmer, cotton trade chain and the country in terms of a quantum leap in cotton production and intangible benefits to the environment since 2002. A recent challenge to the sustenance of *Bt* cotton technology has risen from the evolution of *Bt* resistance in PBW. Cotton is an important cash crop for India and the current PBW issue can certainly be managed through area-wide mitigation measures, consisting largely of the elements of IPM. The first few months of 2017 are critical for action and presents an opportunity to break the pest cycle.

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