The Key to PBW Eradication Was Sterile Insect Technique Coupled With *Bt*-cotton

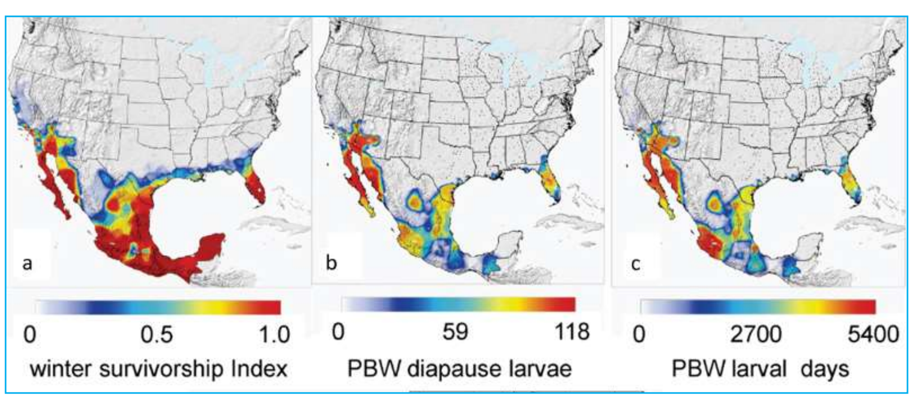
Interview with Prof. Andrew Paul Gutierrez

Prof. Andrew Paul Gutierrez FRES is Professor Emeritus in Ecosystem Science, College of Natural Resources, University of California at Berkeley, CA, USA. His research group investigates plant - herbivore-natural enemy interactions as driven by edaphic and weather factors using physiologically based tritrophic models. Prof Gutierrez is the CEO of CASAS Global NGO (http://www.casasglobal.org) which is dedicated to analyzing issues in diverse crops, rangelands, and medical and veterinary vectors to benefit populations and governments in developing countries worldwide. Prof. Gutierrez is the recipient of several Awards that include the Robert van den Bosch Medal and Member of IITA/Nigeria team receiving King Baudouin Award. Prof Gutierrez authored four books and more than 270 peer reviewed research papers. He guided 23 Ph.D. students, (1 MacArthur Fellow); 3 MS and 22 Postdoctoral fellows (World Food Prize)

What in your opinion are the factors that may have been responsible for the delay in PBW resistance to *Bt*-cotton in China and USA?

I do not know in detail the conditions in China; hence I will restrict my comments to the USA.

US cotton is mostly industrial scale, and when the exotic pink bollworm (native to South Asia) invaded the southwestern USA, insecticide use skyrocketed, secondary pest out breaks (bollworms, budworms, white fly, defoliators, plant bugs, etc.) became rampant, and yields and profit greatly declined. Agronomists soon developed short-season high-density cottons (SS-HD cotton) that were harvested and the stubble ploughed before PBW could produce overwintering, dormant larvae that would provide inoculum that infested the following season's crop. After a learning and development period with SS-HD cotton, high yields and reduced insecticide use returned, but these procedures required extra effort and costs. When *Bt* cotton became available in the late 1990s, open pollinated *Bt* cotton replaced SS-HD cotton because the costs were acceptable, and it was easier to implement, and pink bollworm proved highly susceptible to *Bt* toxins incorporated in various single and stacked configurations of cotton. However, because *Bt* toxins are insecticides, resistance was immediately recognised as a potential hazard to its sustainability. As noted by many authors on *Bt* resistance management in pink bollworm, the implementation and enforcement of the refuge strategy helped delay resistance development by maintaining a source of susceptible moths within the crop. The use of stacked *Bt* cottons further increased PBW susceptibility and made it more difficult for resistance to the different toxins to develop. In addition, the use of pheromone and sterile males SIT technologies reduced PBW populations regardless of their resistance status. The costs of these technologies were relatively small and government and state extension services oversaw their development and implementation. So it was a combination of all of these factors at different times that helped delay the development of resistance in PBW. Figure 1 shows the climatic limits of PBW in the USA.



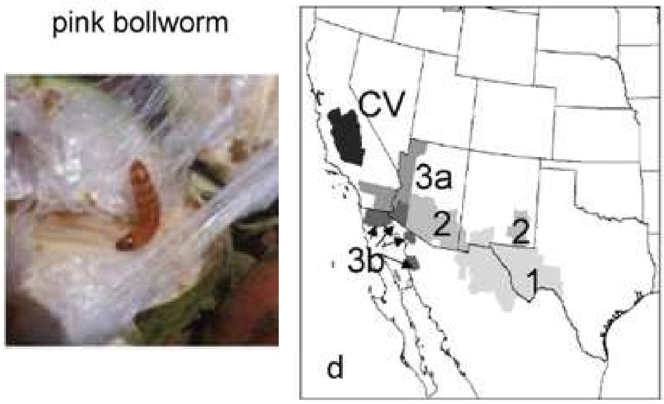


Figure 1. Geographic limits of pink bollworm in the southwestern USA: (a) cold weather limits as measured by winter survivorship indices, (b) the number of PBW larvae m^{-2} during the season, (c) cumulative larvae days during the season, and (d) the different phases of the PBW eradication program (see text, modified from Gutierrez and Ponti 2013).

What could have been the main reasons for the rapid development of PBW resistance to *Bt* cotton in India and Pakistan?

In contrast to the southwestern USA, cotton production in South Asia is mostly by millions of small-scale producers with most cotton being rainfed, and PBW is a native key pest having no effective natural controls. Prior to the introduction of *Bt* cotton to India beginning in 2002, insecticides to control the key pest PBW in long season cotton was increasing with expected outbreak of secondary pests (analogous native secondary pests such as 'American bollworm') leading to reduced yield, increased costs, and environmental issues. With the introduction of *Bt* cotton, there was initially an improvement, but predictably, resistance to insecticides and to *Bt* cotton began to arise. The major factors were the lack of consistent employment of refuges for resistance management due to scale and lack of extension infrastructure. Figure 2 shows how the refuge strategy would affect the time development of resistance in PBW. (Figure 2)

PBW has become a serious menace in India and Pakistan in recent years on *Bt*-cotton. What could have been the reasons for resurgence in pestilence?

In addition to the development of resistance to *Bt* toxins in PBW, insecticide use began to increase, and secondary pests not controlled by *Bt* toxin (white fly, plant bugs and *Bt* resistant defoliators, see Figure 3 below) increased, so that by 2012 insecticide use in India had reached pre-2002 levels, and Indian farmers were on both the insecticide and biotechnology treadmills. (Figure 3)

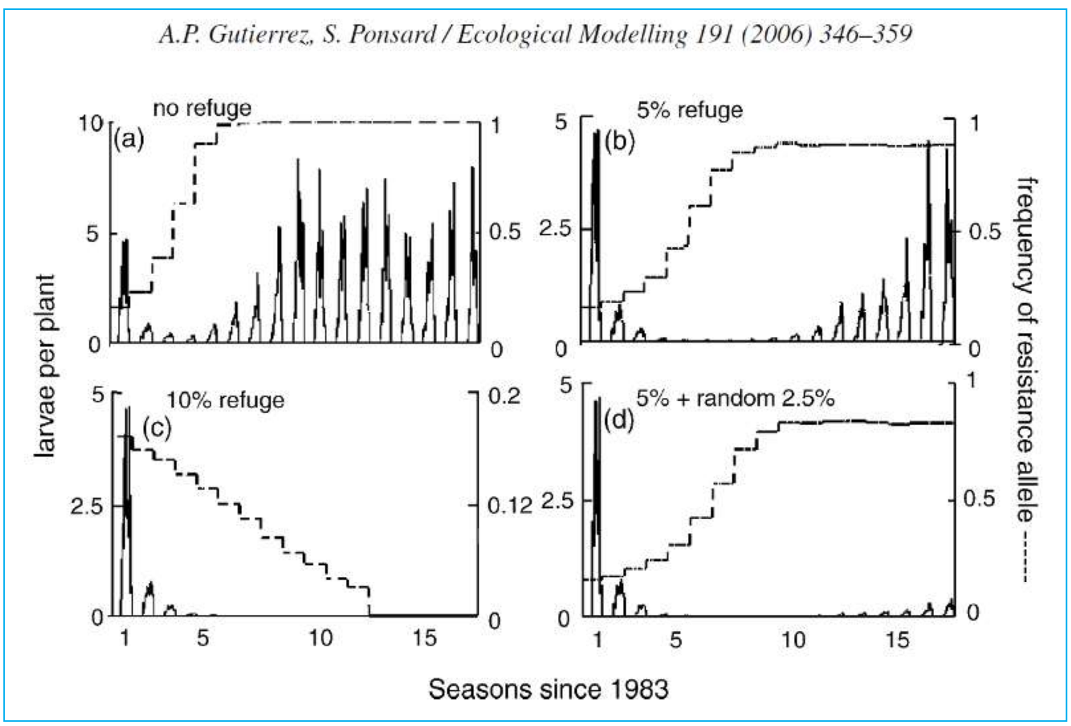


Figure 2. The potential development of resistance in PBW under different refuge conditions (Gutierrez, A. P and S. Ponsard, 2006. Physiologically based model of Bt cotton-pest interactions: I. Pink bollworm: resistance, refuges, and risk. Ecological Modelling 191:346-359).

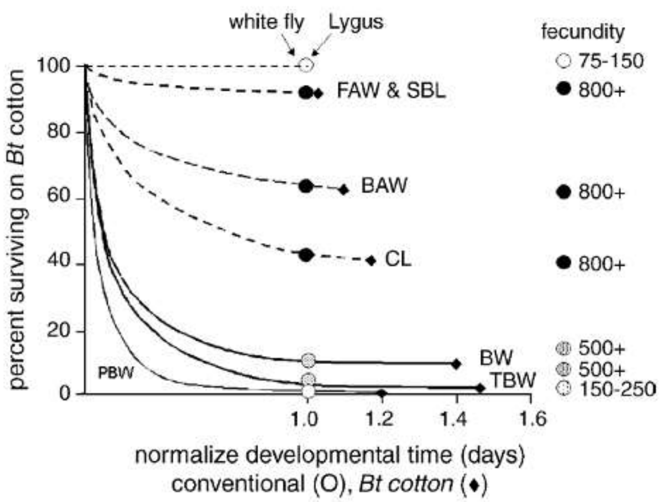


Fig. 3 The percent survival on normalized developmental time. Developmental time on conventional cotton is depicted by symbol shape ○, while that of survivors on Bt cotton is indicated by (♦). Relative measures of fecundity are indicated on the right hand margin. Abbreviations are: whitefly (WF), *Lygus* bug (*Ly*), fall armyworm (FAW), soybean looper (SBL), beet armyworm (BAW), cabbage looper (CL), bollworm (BW), tobacco budworm (TBW), pink bollworm (PBW).

Figure 3, Relative susceptibility of various secondary pests in SW USA cotton (Gutierrez, A. P., J.J. Adamcyzk Jr. and S. Ponsard. 2006. A Physiologically based model of *Bt* cotton-pest interactions: II. bollworm-defoliator-natural enemy interactions. Ecological Modelling 191: 360-382.)

Which technologies held the key for PBW eradication in USA?

The key to PBW eradication was the suppression of PBW to very low levels by *Bt* cottons, that set the stage for effective use of sterile insect technique (SIT) on a regional level (see stages of the eradication program in **Fig. 1d** above). Without the suppressive effects of *Bt* cottons, SIT would not be effective as shown by SIT eradication attempts prior to the introduction *Bt* cotton.

In your opinion, will implementation of strategies such as 'refuge in a bag', 'sterile moth release' and 'pheromone mating confusion' work for resistance management or pest management in India and Pakistan?

The answer is no, because these technologies are expensive for poor farmers who largely lack the appropriate infrastructure to successfully implement them. The refuge in a bag approach of mixing non *Bt* seed with incredibly expensive hybrid *Bt* seed (unique to India) provides little net gain for farmers. The pheromone confusion approach didn't work in the USA and would be less likely to work in India, while SIT releases would need massive government intervention on a scale that dwarfs that attempted in the southwestern USA and Mexico, and worse the conditions for effective SIT are lacking (see map Fig.1)

Which strategies would you recommend for India and Pakistan for sustainable management or eradication of PBW?

What has been lacking are holistic methodologies for assessing the effects of weather on cotton/pest interactions – to enable rapid evaluation of scenarios. To see why in California, SS-HD cotton and post-harvest ploughing saved the irrigated cotton industry from the invasive pink bollworm by curtailing the development of dormant overwintering stages. The same methods in India show how rainfed SS-HD cotton would largely avoid infestation by adults emerging from winter dormancy in the various regions. Currently, the use of expensive effectively infertile hybrid *Bt* long season cottons limits planting densities and hence potential yields.

For India, field trial data show that pure-line short-season (SS), high-density (HD), non-GM rainfed varieties are a viable alternative to hybrid *Bt* varieties. Rainfed SS-HD cotton would largely escape pink bollworm infestation and the build up of late season pests. This would greatly reduce the need for insecticides, allow seed saving, and double yield and increase net income, and likely reduce suicides. (Figure 4)

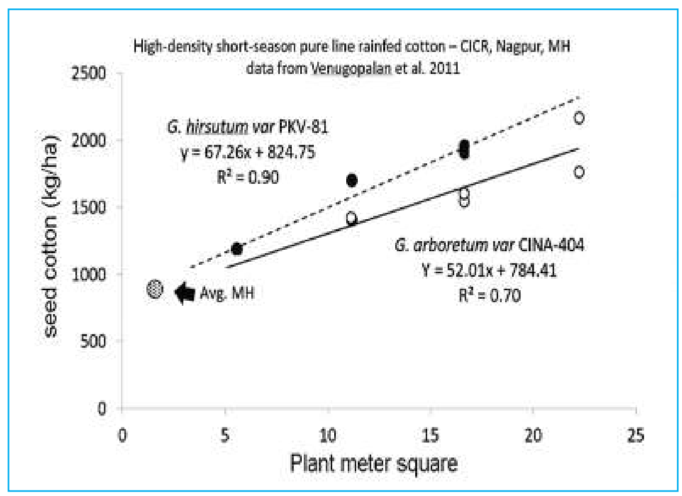


Figure 4. Seed cotton yields: average for Maharashtra for current hybrid *Bt* cotton (◉) and, field density trials of (●) *G. hirsutum* and (○) *G. arboretum* high-density short-season pure line cottons at CICR, Nagpur, India[13,15].

The hybrid *Bt* technology is incompatible with the SS-HD technology, because GM seed costs would greatly increase due to the higher seeding rates without commensurate increases in yield and would prevent seed saving. Cotton grown organically would increase profit, improve soils through reduced exposure to toxic chemicals and lower input costs, and reduce dependency on money lenders to cover productions costs. Fertile pure-line SS-HD non-GM cottons have been available for quite some time in India, but have not been widely implemented, and the obvious question is why? However, despite their utility, SS-HD cotton varieties are not a guarantee against the *gamble of the monsoon*, but they would lessen the impact.