bloom initiation and peak bloom. HDSS varieties will not escape pink bollworm in this scenario. Thus HDSS is a new initiative for enhancing cotton productivity, but should be endowed with *Bt* traits for long-term sustainability. Lastly, refuge-in-bag should be the refuge delivery mechanism for extended product durability.

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Response:

It is important to have an open discussion about the unique hybrid *Bt* cotton (new world *Gossypium hirsutum*) adopted in India, but it is also essential to have a clear understanding of the ecology, phenology and dynamics of cotton and cotton pests that underpin the problem. We must distinguish between target key pests (e.g. pink bollworm, *Pectinophora gossypiella*) and secondary pests (e.g. American bollworm (*Helicoverpa armigera*), sap-sucking insects such as whitefly, mealybugs and others) that arise under insecticide disruption and are often more damaging than the initial target key pest. We must also know whether and when insecticides and the *Bt* technology are truly needed – to understand why some growers can produce organic cotton in India. Prior to the 1970s, when extensive insecticide use began, bollworm and whitefly were minor pests in Indian cotton, and what is obvious is that *Bt* hybrid technology was introduced to solve an insecticide-induced bollworm problem. Given this, India is not faced with a false binary choice between unrestrained use of insecticides as done during pre-2002 and currently or further *Bt*(s) technology adoption. Both of these options are based on linear thinking and are akin to a technological dog chasing its own tail. A systems model of cotton and of pests enabled sorting out many of the details in North American cotton, and this bit of technology might be useful in India[1,2].

The extensive use of insecticides in India began pre-2002 with the introduction of long-season non-*Bt*-hybrid cotton that induced secondary pest outbreaks of bollworm. With *Bt*-cotton adoption to control bollworms, there was an initial decline in insecticide use from 2002, but it increased after 2007 and by 2012 was at pre-2002 levels; however, it now targeted *Bt*-resistant bollworms and new secondary pests not controlled by *Bt* toxins (e.g. whitefly, mealybugs and other sucking insects). Secondary pest problems are caused by insecticide ecological disruption as has occurred worldwide[3] and hence it is not unique to India. It was the root cause of the disaster in cotton in the Great Central Valley of California during the 1960–70s, when massive outbreaks of secondary pests (native bollworms, defoliators, mites) were induced by insecticide misuse[4,5]. However, once the ecological basis of the problem was understood in cotton in the area, the crop could be grown largely insecticide-free and without *Bt* technologies, and secondary pests returned to their natural low levels.

In India, the costs of hand-pollinated long-season *Bt* cotton hybrid varieties are very high and result in suboptimal low plant densities (~2.5 plants m^{-2}) that contribute to low stagnant yields which are further influenced by weather. These unique hybrid cottons are used as a value-capture mechanism that does not appear to benefit resource-poor farmers with increased yield[6]. In industrial cotton in other parts of the world, open-pollinated fully fertile *Bt*-cotton varieties are used successfully because yields are vastly higher, *Bt* seed costs are lower, *Bt* varieties are effective in controlling key lepidopterous pests such as pink bollworm, resistance to *Bt* toxins is avoided using non-*Bt* refuges, most farmers have learned that they must minimize insecticide use to avoid secondary pest outbreaks, and intellectual property rights (IPR) against seed-saving and replanting are controlled by legal means. In China, fully fertile *Bt* hybrid cotton has been developed by crossing fully fertile *Bt*-cotton and non-*Bt*-cotton to create F1 hybrids that are hemizygous for the *Bt* trait[7]. Self-pollination of these fully fertile F1 hybrids produces F2 hybrid seeds for planting that are 25% *Bt* homozygotes and 50% *Bt* hemizygotes, and 25% non-*Bt* homozygotes. In the field, the 75% *Bt* portion of the F2 cotton plants controls pink bollworm and bollworm, while the non-*Bt* fraction acts as a refuge for preserving susceptibility in the pests to *Bt* toxin serving to delay or eliminate the development of resistance. This is a form of the refuge-in-the bag approach. These F2 cotton hybrids are fully fertile and hence would not be useful as a value-capture mechanism in India, where farmers would simply save seeds and replant them the following season, resulting in an erosion of commercial IPRs. I suppose mixing non-*Bt* seeds with current Indian hybrids could provide a refuge, but this begs the question of the high price of seeds and the lack of yield benefit from the current Indian hybrids. What should be obvious is that neither unrestrained use of insecticides nor the current *Bt* hybrids technology with the addition of any number of *Bt* traits provides the answer for resource-poor farmers in India. This conundrum is why Indian Government incentives are required to develop appropriate varieties and integrated pest management (IPM) strategies. The current vicious dystopic cycle needs to be broken, and the adoption and modification of open-pollinated rainfed high density short season (HDSS) cotton technology would a big step in that direction. As an important aside, incorporation of *Bt* and other genetically modified (GM) technologies in indigenous 'desi' cottons (*G. arboreum* and *G. herbaceum*) and food crops must be avoided to prevent contamination of seed stocks.

Rainfed HDSS varieties of cotton would provide a viable option for Indian cotton farmers under rainfed and irrigated farming conditions, but like any cotton, would still be at the mercy of rainfall patterns and amounts. In California, HDSS cotton was successfully cultivated under irrigation to control pink bollworm, but it required training on planting and stalk destruction at the end of a well-defined season to reduce/destroy dormant overwintering pink bollworm pupae. Rainfed HDSS varieties in India would largely escape the emergence of overwintering pink bollworm pupae, would reduce the build-up of late-season populations, and stalk destruction would greatly reduce the production/survival of overwintering diapause (dormant) populations. Analysis of the phenology of pink bollworm dormancy would sort out fact from fiction concerning this key pest, and would define how HDSS could be implemented to reduce pest populations regionally, including infestations of pink bollworm arising from susceptible, early-planted, long-season irrigated cotton[8]. Implementation of HDSS technology requires that sound information reaches resource-poor farmers, who currently appear to get their 'information' from insecticide/seed sales persons and not well-trained IPM or Government specialists. Continued sale of high-cost, value-capture hybrid *Bt* seeds and indiscriminate use of insecticides are hard-learnt, nonviable options.

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