been lost (Napolean in Russia due to typhus), the direction of the march of civilization determined (Chinese Empire and silk trade) and populations decimated through the direct involvement of insects, usually as carriers of disease (plague in Europe in the 14th century). The work and life of scientists have been cut short due to insects, as is evidenced by the likely cause of death of Charles Darwin, who contracted Chagas disease after being bitten by the reduviid 'kissing' bug during his *HMS Beagle* voyage to Chile in 1835 (ref. 2).

There are anecdotes of a number of ways in which insects have crept into our lives. A moth is supposed to have prevented an accident of a train on which Queen Victoria was riding. The moth was attracted to the head light of the train and in the fog the flapping wings of the moth looked like the image of a man flagging the train to stop. The driver jammed the brakes and later found that the bridge ahead had collapsed; thus an accident was averted by the moth. The Chinese inventor of paper Ts'ai Lun (AD 89–106) is believed to have been shown the process by wasps making their nests by chewing tree bark and mixing it with their saliva. 'Butterflies in my stomach' is a common expression to convey anxiety, fear, nervousness about a forthcoming activity and the feeling very aptly describes what it must feel like to actually have real butterflies in your stomach, fluttering and sitting on your stomach walls.

Almost no aspect of our culture and history is untouched by these creatures. In spite of a hard exoskeleton, extra appendages and robot-like instincts, insects sufficiently parallel humans in structure and behaviour to serve as models in various human activities. A good example is the navigational and cognitive capacities of ants and honey bees with brains weighing just a few milligrams, which are lessons for us in traffic regulation and management and for solving the problem of a 'travelling salesman' for the most efficient itinerary to visit different locations. There is a dire need to explore our classics, history, culture, music, religion, poetry and prose, recreation, museums of art, archaeology, anthropology, psychology, science and technology and all around us for more evidence of insects in our lives. Studies in 'cultural entomology' could be useful in understanding the role of insects in all facets of humanity, and provide an insight into our attitudes towards insects in particular and nature in general[3]. This would vastly help project entomology from being an 'esoteric activity' and 'unglamorous subject of study', to one with myriad exciting possibilities in science and humanities.

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Bt and bollworms: clearing a few clouds

Ranjith *et al.*[1] have recently demonstrated the survival and reproduction of the bollworm *Helicoverpa armigera* on *Bt*-cotton hybrids in India. This work has been discussed in the print and electronic media[2–5] for discovering tolerant insect populations. Opinions were also expressed in this journal[6,7]. The intent of this note is to clarify issues, especially the ones that Ranjith *et al.*[1] had to contend with since its publication.

While demonstrating field survival of the target insect on *Bt*-cotton, the study[1] confirmed that the plants were producing *Bt*-toxin. However, toxin concentration in the plant and inherent tolerance in the insect population remained to be quantified. Therefore, while rationalizing the observed survival, both possibilities exist – reduced toxin concentration and enhanced tolerance. This has been highlighted in some later articles[6,8]. One of the prominent opinions expressed was that the environmental state during the year of study (2009) may have reduced toxin concentration in the plant[6]. To verify this, we looked for deviations in three major climatic elements – temperature, relative humidity and rainfall between 2009 and the respective average values for the preceding 22 years (1986–2008) at Raichur. Figure 1 shows that with the exception of rainfall, the other two factors were near normal for 2009. What is interesting is that rainfall was higher than normal during 2009, and one expects higher moisture to increase toxin concentration in the plants[9,10]. Moreover, plants were subjected to optimum growth conditions under the supervision of the University of Agricultural Sciences (UAS), Raichur. Yet, the pest thrived on *Bt*-cotton.

The effectiveness of *Bt* hybrids decreases when concentration of the toxin significantly varies with factors like environmental states[11]. In this connection, we suggest that regulatory authorities take cognizance of data on the extent of variation in the concentration of *Bt*-toxins against different environmental states for the present and future commercial *Bt*-hybrids. Conditions that may be inappropriate for the expression of the gene should be clearly mentioned for each hybrid. This, on one hand, would assist farmers to take precautionary measures when climatic or other factors vary beyond sensitivity limits of the hybrids. And, on the other, scientists will be able to verify the hypotheses before interpreting insect survival.

Field entomologists, interested in working independently on the efficacy of *Bt*-cotton, find it hard to estimate the extent of resistance in insect populations due to difficulties in obtaining pure toxins in the country. They have to depend on the technology providers for pure toxins, which, sometimes, can impede independence in research. To overcome this, a Government or an independent body may maintain a repository of each gene-toxin, which, upon request, may be made available to any researcher. A similar repository is maintained in China by the Chinese Academy of Agricultural Sciences[12].

The published paper[1] is criticized[6] for letting insects enduring *Bt*-cotton to mate among themselves, which may have been responsible for the observed survival of the next generation. This is claimed to be far from 'field reality', where resistant individuals surviving on *Bt*-cotton are expected to mate with the susceptible population surviving on refuge crops (non-*Bt* crops cultivated adjacent to *Bt*-crops that serve as refuges for target insect populations). However, there is no direct scientific evidence to prove the above-mentioned field reality; all that is said is based completely on theory. The strongest evidence to support the concept comes from a recent review[13] that shows lower number of reports claiming resistance in target pests in countries where refuge crops have been strictly planted. To surmise, there is no field reality or theoretical confirmation of the concept even after a decade of adoption in India. This confirmation would be necessary considering that the concept of cultivating refuge crops arose in the US, where farming systems completely contrast those in India. Moreover, in India, farmers are reluctant to cultivate refuge crops[14,15]. Preliminary results of an ongoing study at UAS, Raichur show > 90% non-compliance among farmers in Karnataka, Andhra Pradesh and Maharashtra for cultivating refuge crops (unpublished data). Under these situations, it would be fair to state that the published paper[1] is not far from field reality. Coming back to the criticism about forced mating among surviving individuals[6], we would like to stretch it to the insects sampled directly from *Bt*-cotton fields[1]. Parents of this generation were not forced to mate with any 'chosen' partner. Nevertheless, they successfully completed their development and reproduced on *Bt*-cotton plants[1]. Further, if field-collected individuals were just as susceptible, the resultant progeny, when bred on *Bt* plants, should have had low survivability than that of individuals bred on non-*Bt* plants (control), which was not the case[1]. Additionally, if a few hundred tolerant moths are packed in a not-so-large space[1], a decent probability of mating can be expected among them. It is high time to generate empirical data to verify field realities. National policies on planting refuge crops appear to be based on untested theories.

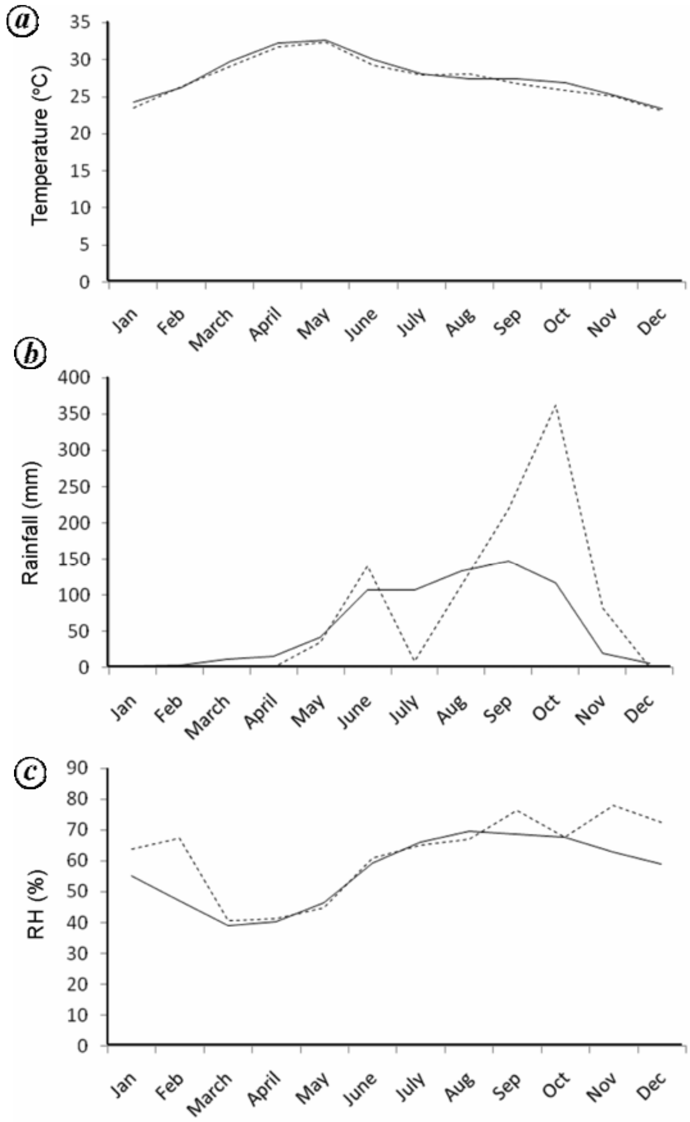

Figure 1. Month-wise comparison of (***a***) daily average temperature (°C); (***b***) rainfall (mm) and (***c***) relative humidity (%) between 2009 (dotted lines) and the cumulative average from 1986 to 2008 (solid lines) at the University of Agricultural Sciences (UAS), Raichur. Data were drawn from the Meteorological Department, UAS, Raichur.

While comparing *Bt* genes with conventional insecticides, the former can be referred to as internal toxins and the latter as external toxins; the commonality stems from a 'toxin' approach to curtail insect populations and the discord is in their modes of delivery. Today, there are two internal toxins in the same cotton plant and it has been shown that the insect is able to survive both in the same plant[1]. In response to the results, one of the suggestions has been to have further gene pyramids (piles of internal toxins in the same plant) to tackle such situations[2]. Now, one can see where this is going – from a cocktail of external toxins to a cocktail of internal-plus-external toxins (because insects unaffected by target-specific internal toxins are to be 'sprayed' anyway). In this situation, it appears imperative to recalculate the advantages of internal toxins.

The insect found surviving on *Bt*-cotton, *Helicoverpa armigera*, is arguably the most prominent insect-pest in India that affects a number of agricultural crops – cotton, pigeon pea, lady's finger, sorghum, chickpea, tomato, corn, etc. In India, many of these crops are being inserted with the *Bt* gene, which is already a part of the cotton genome[16]. This means that the insect is by now under selection by the *Bt* gene, even before its new *Bt* hosts get commercialized. Gene–crop interaction, in terms of quality of toxin produced, cannot be expected to be significant. Therefore, late-arriving

Bt-modified crops may face an early onslaught of 'selected' insect populations[17]. In this case it would be difficult to blame non-compliance in cultivating refuges in India. The solution will be new genes dictated by 'time'. An interesting gene-mix awaits farmers who wish to genetically manage insect-pests.

Survival of insects on *Bt* crops is of concern to a farmer. Factors responsible for survival do not bother him directly. Reasons for survival have become important in scientific discussions and survival per se has been sadly downgraded. As of now, it is important to agree upon the fact that insects are able to survive and reproduce on plants that are expressing the gene. The Indian farmer does not get his money back for underperformance of the gene, irrespective of the reasons. There is no 'guarantee period' for effective performance of a gene in *Bt* crops, as it is for many commodities in a supermarket, where, for whatever reason, failure of the product within the guarantee period draws penalization. Currently, it looks like the focus is on technology and not on the farmer. The farmer in this country is hardly educated about the technology; he is vulnerable to both pro- and anti-technology groups (as used in common parlance today); strengths of corporate strategies or strengths in the denials of 'green activists' determine his thoughts. He is left with no choice today; non-*Bt*-cotton is completely off the retailers' shelves. There is a need for providing an unbiased education to the farmer and to offer him choice. Advantages and risks are to be made clear to him.

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