The chip is what IT is about!

This year the Nobel Prizes in Physics and Chemistry have been awarded for experimental discoveries in the realm of Condensed Matter which have revolutionized (to use a much-abused word!) technology. The Physics awards have been made to Zh. I. Alferov of Russia working at Ioffe Institute at St Petersburg and to Herb Kroemer, earlier at RCA, Princeton, USA and now at the University of California, Santa Barbara, USA for 'developing semiconductor heterostructures used in high speed optoelectronics'. Half the award has been given to Jack Kilby of Texas Instruments (TI), for 'his part in the invention of the integrated circuit'. Interestingly enough, the work for which the trio have been recognized was all done long back, starting in the mid-fifties in the case of Kroemer and Kilby and in the sixties in the case of Alferov. Is it because the Nobel Committee wanted to correct an oversight or is it because the impact of these discoveries are being felt only now?

Kilby is recognized as the 'father of the silicon chip' – the first integrated circuit was designed and fabricated by him at TI in 1958. This claim was disputed by Robert Noyce of Fairchild Semiconductors, USA resulting in protracted litigation, which was finally patched up by the two companies in 1966. This award for a technological breakthrough is a landmark of sorts. The discovery of the transistor by Bardeen, Brattain and Shockley was recognized by the Nobel Prize in 1956. Bardeen had trouble believing that the invention of the transistor was worth a Nobel Prize. 'It was important technologically, but was it a major advance in physics?', he asked. In the seventies, when he visited the Indian Institute of Science, Bangalore. Bardeen told the present author that he considered his theory of superconductivity developed with Cooper and Schrieffer and awarded the Nobel Prize in 1972, to be an intellectual effort of an altogether different category. However the transistor – first made of germanium – was the harbinger of the silicon chip. Interestingly, two of the inventors, Bardeen and Brattain, had no idea of the far-reaching impact of their discovery. There is a story that Brattain got an inkling only when he found a camel-driver in Egypt listening to a pocket transistor radio in the early sixties!

Jack Kilby got the idea of integrating the various components that went into making an electronic circuit – resistors, capacitors, diodes and transistors – just after he moved to TI from a smaller firm where he worked on silk-screen printing of printed circuit board. As this company was not geared for semiconductor technology, Kilby took his idea to TI. He attended a short course at Bell Labs, which further crystallized his thoughts and he set about his work during an enforced summer vacation at TI. Although silicon was already being used to make transistors in 1958, Kilby demonstrated the first IC chip using germanium because TI did not have the facilities for silicon processing! The first chip, an oscillator circuit, was patented as a 'Miniaturized Electronic Circuit' and embodied no new physical principle, but was revolutionary (that word again!) in concept, since no one at the time thought of substituting carbon resistors and mica capacitors by semiconductors like silicon.

Robert Noyce at Fairchild Semiconductors on the other hand, based his integrated circuit on the silicon planar technology developed by Jean Hoerni with silicon dioxide as the outer dielectric layer, much as is done today. His patent application a few months after Kilby's was for a 'Semiconductor device and lead structure'. It was granted in 1961, while Kilby's remained stuck with patent examiners, who raised petty objections. Fairchild was the first to market the chip to the US Air Force, while TI was first with the microprocessor and the pocket calculator. Noyce, with Gordon Moore, later found Intel, the largest chip maker today in the US, the originator of the ubiquitous Pentium.

The semiconductor laser was invented by three distinct groups in the USA in 1962 – posing a problem for future Nobel Committees! It was a device that worked only at low temperatures and that too only in a pulsed mode requiring currents of the order of hundreds of amperes. So it remained a laboratory curiosity. It was the work of Alferov and his group in the USSR, competing with similar groups in USA that made it a practical tool for communication. The material used for the first semiconductor laser was gallium arsenide (GaAs), a direct band-gap semiconductor compared with silicon, which has an indirect gap. Alferov, in 1967, was one of the first to show that using confining layers of another semiconductor, aluminium gallium arsenide, (AlGaAs), thus forming heterojunctions, the operating current could be brought down by a factor of 100 to 1000 and the efficiency increased thus permitting continuous room temperature operation.

The contact between the two different semiconductors formed a 'heterojunction' as opposed to homojunctions used in bipolar silicon transistors, now known as bipolar junction transistors (BJT). The technique of laying down or 'growing' layers of semiconductors used by Alferov and his group is called liquid phase epitaxy (LPE) and it was mastery of this technology that powered his invention of the double heterostructure (DH) semiconductor laser. Interestingly enough, Kroemer also independently proposed the use of heterojunctions in lasers in 1963.

The first single heterojunction (SHJ) lasers evolved into double heterojunction (DHJ) devices which not only provided electrical confinement of carriers – electrons and holes – through appropriate potential barriers, but also optical confinement due to differences in refractive index. This is similar to the principle of an optical fibre in that the active region, typically GaAs, has a higher refractive index than the barrier layers, typically AlGaAs.

An interesting race (a mini-olympics) ensued between the USSR and USA as to who could lower the threshold (working) current of such injection lasers and every few months a new record was set. State-of-the-art devices based on quantum wells now require only milliamperes of current – impressive improvement in a matter of thirty years. These devices form the light sources used in present-day fibre-optic communication, permitting unprecedented number of channels at speeds of several tens of gigahertz.

The first GaAs laser in India was fabricated at the Bhabha Atomic Research Centre, Mumbai (BARC) between 1965 and 1966 – a technology gap of only 4 years – and used to send signals to Tata Institute of Fundamental Research, Mumbai (TIFR). The first SHJ lasers based on

GaAs/AlGaAs were fabricated in India by the technique of LPE at Solid State Physics Laboratory (SPL), Delhi. One of the first comprehensive texts on the subject entitled 'Semiconductor Heterojunctions' still widely referred to in the literature was written by Sharma and Purohit of SPL and published in 1974. Studies on semiconductor heterojunctions have since been carried out at TIFR, Mumbai and Indian Institute of Technology (IIT) Kharagpur among other laboratories.

The idea of the heterojunction was first proposed in 1951 by none other than Bill Shockley, one of the discoverers of the transistor at Bell Labs (of fertile mind and unbridled ambition) who left Bell Labs and later found the unsuccessful Shockley Transistors in Silicon Valley. However, it was Herb Kroemer in 1957 who actually designed a heterojunction transistor using this idea. At that time the transistor had a long way to go and the drive was on to get smaller devices manufactured by the millions to operate at higher frequencies. So the idea of heterojunctions had to await the advent of first LPE and then molecular beam epitaxy (MBE) and organometallic vapour phase epitaxy (OMVPE) which allowed the growth of single-crystal layers. Kroemer's ideas came into their own only in the seventies and eighties. The new device that resulted is called the heterojunction bipolar transistor (HBT) which gives improved performance over the conventional homojunction silicon device. The key idea in a HBT is to make the emitter of the transistor out of a wider band-gap material than the base, which improves the efficiency as well as the speed. HBTs are now made of the new SiGe alloy which can be integrated into the Si chip. The fastest devices working at frequencies up to few hundred gigahertz (10^9 Hz) are HBTs made of group III–V semiconductors such as indium gallium arsenide grown on indium phosphide (InGaAs/InP). This is because InGaAs has the highest electron mobility among the commonly used semiconductors and alloys, higher than even GaAs – typically 12,000 cm^2/V.s compared with 8000 cm^2/V.s for GaAs and only 1800 cm^2/V.s for silicon.

Other important applications of heterojunctions are in the fabrication of high-efficiency photovoltaic devices – solar cells. The idea is that semiconductors with different band-gaps can be 'tuned' to different parts of the solar spectrum, which is not possible with a single semiconductor such as silicon. Thus tandem solar cells based on InGaP/GaAs/Ge with band-gaps of 1.9, 1.4 and 0.67 eV, respectively have been developed and used in the latest space satellites to give efficiencies of 28% compared with 16–18% for silicon.

Suggested reading

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Painful lesson from interaction with the media

I suddenly found myself in the middle of a controversy created by the print (*The Sunday Times* dated 28 January 2001) and television (*Zee TV*) media with regard to the 26 January 2001 Bhuj earthquake, much to my regret and surprise. The media have misquoted and misrepresented some of my statements and have used some excerpts from my research papers[1–3] out of context. I have come under the limelight because of my project in the Great Rann of Kachchh. I have been quoted as saying that I had given a warning of the 26 January Bhuj earthquake in a report submitted to the Department of Science and Technology, New Delhi and the warning was ignored by the authorities. I have never said this nor have I ever warned about this earthquake or communicated this by way of any report to any agency. This was a gross misrepresentation of facts. It is true that I worked in the Rann of Kachchh, at the epicentre of the 1819 earthquake, a site located far from the epicentre of the present earthquake. It is true that we have worked out the recurrence period of that earthquake, which is only one of the steps to understand the seismic hazard posed by the fault called Allah Bund, the causative structure of the 1819 earthquake. However, this has no bearing on the prediction of the present earthquake, which probably occurred on a parallel fault, located far to the south. Therefore, qualifying my work in the region as a prediction study of the current seismic event goes against my own understanding of the earthquake processes. What, in fact, I stated was that the Kachchh seismic zone lies in the high-risk region which contained several potential faults and that we should have used this fact and all such scientific inputs, including my work to understand better the long-term seismic hazard of the region. This statement should not have been construed as my warning to the authorities for the impending earthquake. *I wish to place it on record that I have never made any prediction of earthquakes nor have I submitted any report containing this warning.* I have sent rejoinders to the daily, which published the reports containing incorrect statements and quotations. I have also given a statement to the TV channel through telephone, clarifying my stand.

Having learnt a painful lesson from the interaction with the media, I wish to share this with the readers, so that one is aware of such pitfalls.

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Recognition of contribution of a person should be one-time affair

Recognition and appreciation of merit of an individual by making an award, by decorating him with a title, electing him to a body of elites, felicitating him in a meeting or honouring him in some other way, is always welcome in the interest of the discipline in which the individual excels. It encourages and gives satisfaction to the individual, and inspires and sets an example to others. However, doing it again and again for the same person, once by one institution, then by another and so on, makes even the person lose interest in the award or recognition. It looks logical if one is honoured for one's different achievements on different occasions by different institutions. A Nobel Laureate may be honoured by top two or three institutions of the country, but if there starts a race/competition amongst different institutions for felicitating him, it more or less becomes a 'tamasha'. However, the Nobel Prize or Gandhi Peace Prize or the like may be an exception. Less significantly one is generally recognized as literateur, musician, sportsperson, social-worker, physicist, chemist, etc. for one's life-time contribution in his field. It is also true that there would be not one, but several or at least a few such persons in each field, who may deserve to be recognized. Recognition of equally meritorious or a little lesser persons is delayed or ignored, and this may hamper the progress of the discipline concerned. While giving an award in any subject, due attention has to be paid to all the broad areas, but only if and when excellence has been shown by someone in the field. The art of teaching, teaching methods and development of instrument of teaching in a subject should also be taken care of for the recognition.

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Bt-cotton in India

The article '*Bt*-cotton in India: Anatomy of a controversy' by Geeta Bharathan (*Curr. Sci.*, 2000, **79**, 1067–1075) is an overall admirable analysis of the controversy regarding the application of genetic engineering (GE) (or genetic modification using recombinant DNA technologies (GM) or transgenics as more widely used) for the improvement of crop plants. It raises many questions, a few are genuine, others reflecting some of the exaggerated concerns that have been raised earlier[1]. However, the analysis, though intellectually stimulating, is based on incorrect information and shows a lack of familiarity with the variety development and evaluation process (basic plant breeding and genetics).

Foremost, the author has mixed up two issues – Government of India not buying the *Bt*-cotton technology package from Monsanto using public money, and essentially the import of the same *Bt*-cotton by MAHYCO, a private seed company in which Monsanto later acquired 26% share. The main reason for the Government not accepting the Monsanto offer was the high cost to the public funds. Later the transgenic *Bt*-cotton seeds were imported as a commercial deal between MAHYCO and Monsanto. No public funds were involved in this transfer.

Hence, the event listed in table 1 of the above-mentioned article as 'Monsanto refused permission to backcross Bollgard into local varieties to get *Bt*-cotton' is not correct. Also the final refusal to Monsanto was in 1993 and not 1990. Thus the author's conjecture that 'One factor might be the fact that a MNC made the application in the first instance, while an Indian company did so in the second' is not correct. These incorrect inferences give wrong signals to the MNCs at a time when the country is looking for foreign investment in the agricultural sector, and other MNCs are waiting to transfer their GM varieties in India.

Similarly, in table 2 of the article, some of the features (I) and their implications (II) such as 'Not a simple case of introducing specific gene with a known effect. Sufficient period for effective screening', 'Scale of trials: 1 acre plots – 1 acre tests too small', 'Period of trials: 2 seasons, 1 to 2 seasons too short' questioning the project design are not correct. These are standard plant breeding practices. Both public sector plant breeders and private seed companies have limited resources for experimental testing of new materials.

'Farmers' lack of familiarity with pests in new cotton-growing areas', 'Inappropriate pest management', and 'ineffective transfer of technology' have no relationship to *Bt*-cotton which is yet to be approved for commercial cultivation in the country. Insect pest problem in cotton cultivation is not something new. 162 species of insects are known to be associated with cotton crop in India, of which 12 are considered as major pests[2]. It is well established that host plant resistance/tolerance helps in suppressing the pest population at low cost, and also reduces the use of chemical pesticides, thus causing less environmental perturbation. DDT, BHC, organo-phosphorus compounds, pyrethroids, besides NPV, bio-control agents, including *Bacillus thuringiensis*, pheromones, botanical pesticides like *Neem*, *Karanj* and garlic extracts, and integrated pest management have all been used to control cotton pests[2]. Chemical pesticides were effective initially, but later insect biotypes resistant to the pesticides have emerged. At present, *Bt*-cotton provides the best available host plant resistance and with integrated pest management can considerably reduce yield losses and pesticide use. *CryIAc* alone may not be the best strategy[3], but that is the one readily available for introduction in the Indian cotton hybrids. Other genes to develop more effective stocks are available, but to develop transgenics and bring them to a level that they can be grown commercially, takes a long time. Local efforts currently in progress would take at least 10 years to reach the level already attained by MAHYCO. What MAHYCO has done is the best possible strategy, and the same should be followed by all developing countries, to utilize GE for the improvement of their crops. The ultimate test of the new crop varieties is the benefits realized by the farmers in terms of net returns, and their acceptance (willingness to pay for the value-added seed). From the business viewpoint, *Bt*-cotton providing insect resistance is a need-based 'product' with a large potential market. The most serious environmental risk it poses is the possibility that the *CryIAc* gene may be transferred to other cotton varieties through outcrossing[4]. The probability of its moving to wild, related species is almost nil as wild species of genus *Gossypium* are not found in the neighbourhood of cotton fields and the cytogenetic barriers[4]. Moreover, such spread of the *Bt* gene cannot cause adverse environmental effects. The other risk of the breakdown of resistance due to increase in the population of already existing resistant insect biotype or due to new mutations is a part of resistance breeding[3]. Plant breeders incorporate new *R* genes while insects and pathogens, for their own survival, evolve mechanisms to overcome the resistance[5,6].

Further, the author says '. . . Distortion of these facts by the media may have led to exaggerated response by the public'. Yet the analysis is based on at least 8 citations from popular media – *Business Line*, *Frontline*, *The Hindu* and *The Hindustan Times*.

The questions raised by the author on the scientific aspects of GE technology need no comments. The Royal Society of London, the US National Academy of Sciences, the Indian National Science Academy, the Brazilian Academy of Sciences, the Chinese Academy of Sciences and the Third World Academy of Sciences in their report[7], based on expert evaluation, and extensive discussions have recommended the use of GM technology. With respect to pest resistance the report says: 'There is clearly a benefit to farmers if transgenic plants are developed that are resistant to a specific pest'. Further it says: 'There may also be a benefit to the environment if the use of pesticides is reduced. Transgenic crops containing insect-resistance genes from *Bacillus thuringiensis* have made it possible to reduce significantly the amount of insecticide applied to cotton in the USA'.

The social issues are much more complex in India. GM crops were widely accepted in North America and the area cultivated with GM crops increased rapidly. In 1999, the area under GM crops was 28.7 (US), 4 (Canada), 6.7 (Argentina) and 0.3 million ha (China)[8]. The opposition to GM crops was initiated by the Union of Concerned Scientists in US[1], followed by Greenpeace in Europe. Gordon Convay[9], President of the Rockefeller Foundation attributes the European opposition to GM crops as 'the worry of the domination of food chain by American companies'. Others[10] attribute it to lack of economic imperatives among the farmers due to Government subsidies. In India cotton is very important for the national economy and directly or indirectly provides employment to a large number of families in handloom, powerloom, textile and garment industry[2,11]. For many *Bt*-cotton represents an imported technology controlled by a MNC, protected under the IPR, the seeds of which would be sold by a private company partly controlled by MNC; and since these are hybrids, farmers will have to buy seeds from the company every year. People fear that participation of the MNCs in the seed industry would lead to subjugation of the Indian farmer. In the changed scenario, to be globally competitive, what matters is the quality of the produce and the production cost. While intensifying cotton production, the pesticide load on the soil and environment in the growing areas should be minimized. The new textile policy[12] envisages exports to the tune of 50 billion US dollars annually by the year 2010 from 11 billion at present. *Bt*-cotton can certainly make its contribution towards reaching this target. Besides the questions raised by the author, the adverse impact on production, productivity, quality, production cost and environment by not accepting the *Bt*-cotton also need to be examined using sound scientific data.

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Response:

Bhatia states that the main difference between the Monsanto and MAHYCO projects lies in the fact that no public funds were involved in the latter; that *CryIA(c)* is currently the most appropriate gene, given the time lag in developing other genes for the purpose; that the scale of trials (area and duration) is within standard practice, given limited resources; that evolution of resistance in insects and pest management is general problem in crop improvement; that few scientific issues of concern remain regarding GE technology; and that societal issues, such as fears surrounding intellectual property rights (IPRs), cannot be given importance while entering the global market. My comments are on two scientific aspects: (i) pest resistance in *Bt* cotton, scientific issues in GE, and (ii) societal aspects (*Not* directly related to the *Bt* cotton project): transparency of the regulatory process, and IPRs.

● *Pest resistance in Bt cotton*: While pest resistance is a general issue, resistance to *Bt* crops may evolve faster than to traditional pesticides, therefore management plans need to be clearly laid out at the outset (see my response to Barwale's comments).

● *Ecological impacts and GE*: A recent review (Wolfenbarger, L. L. and Phifer, P. R., *Science*, **290**, 2088–2093) states that '. . . key experiments on both the environmental risks and benefits are lacking. The complexity of ecological systems presents considerable challenges for experiments to assess the risks and benefits and inevitable uncertainties of genetically engineered plants'. Therefore, rather than dismiss the potential for negative environmental impacts, regulatory procedures should ensure that the potential risks and any corrective measures are initially spelt out so that appropriate monitoring can be done, with follow-up as necessary.

● *Availability of information*: Bhatia questions my use of newspapers as a source of information after having commented on distorted facts in the media. This fact reinforces my point that information needs to be accessible: I had to use newspapers largely because other sources of information on these matters are not easily accessible to someone not directly involved in this work. I strongly urge the Department of Biotechnology and the Department of Environment to make public information on developments at various stages of the regulatory process, via a website, as done in the US by the United States Department of Agriculture (e.g. http://www.aphis.usda.gov/bbep/bp/) and Environmental Protection Agency (e.g. http://www.epa.gov/fedrgstr/index.html).

● *Intellectual Property Rights*: Bhatia notes that many Indian farmers fear the entry of multinational corporations (MNCs) into seed production in India since, to them, it spells the end of seeds as public goods (and he feels that the need to be globally competitive outweighs such concerns). The issue of IPRs is intimately tied up with the advent of MNCs, and this nexus of forces is feared by many people. These fears are likely to recur unless it is clear that the public interest is held above other interests. Contrary to common impression, there are a few signs that the dreaded 'terminator technology' is a thing of the past (e.g. Rafi, Suicide seeds on the fast track, http://64.4.69.14/web/allpub-display.shtml?pfl=com-list-all.param), and the public should continue to be aware of such facts. Other patent-associated problems, such as surrounded carotene-enriched 'golden rice', need to be addressed: e.g. 'Enabling Technologies', at the Centre for the Application of Molecular Biology to International Agriculture (http://www.cambia.org/main/r_enab_tech.htm). All options should be explored in imaginative ways and not foreclosed in an attempt to save time.

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Bt-cotton: Government procedures

Geeta Bharathan (*Curr. Sci.*, **79**, 1067–1075) has touched upon several aspects of *Bt*-cotton in India, some of which are inexact and are not based on facts. It is the intention of this note to provide clarification on the working procedures of the Government on the *Bt*-cotton trial, which are elaborated below:

● Permission for conducting contained field trials for collection of data was accorded by the Department of Biotechnology (DBT) for *Bt*-cotton hybrids containing *Cry1Ac* gene to M/s Maharashtra Hybrid Seeds Co Ltd (MAHYCO), Mumbai and not to M/s Monsanto. All the testing and evaluation work is being done utilizing the cotton hybrids of MAHYCO, and these hybrids are designated by the prefix of MECH with a numerical suffix, but not with the designation of Bollgard.

● There was no committee headed by V. L. Chopra that rejected the induction of the *Bt*-cotton technology at any stage. The initial negotiation for technology transfer between India and Monsanto was for a package comprising the supply of two constructs containing *Cry1Ac* as well as *Cry1Ab*, transformed *E. coli* competent to express these two *Cry* genes, and transgenic cotton seeds of Coker-312 containing *Cry1Ac* gene, besides including training of Indian personnel in molecular biology relevant to cotton transformation. This negotiation broke down because of disagreement between the Government of India and Monsanto on financial terms of the technology transfer.

● MAHYCO's proposal for importing transgenic cotton seeds of Coker-312 containing *Cry1Ac* gene was for investigating step-by-step the basis for the insertion of the *Bt*-transgenic traits into Indian cotton cultivars by backcrossing using the Coker-312 as the parent line; establishing the stability of the back crossed cultivar; assessing the quantum of expression of *Bt* proteins in different plant parts; evaluating the efficacy of the transgenic plant parts against the target bollworm; assessing the environment risks of the transformed *Bt* cultivars in Indian germ plasm; and evaluating the food safety of the *Bt*-cotton on experimental animals. This proposal was approved in the research mode to MAHYCO in accordance with the existing rules. This is consistent with the Indian Environment (Protection) Act (EPA 1986), and Rules 1989.

● It is, perhaps, therefore, not fair to state without full knowledge about the facts as has been mentioned by the author (p. 1069). 'The factors that led to the approval of a project that, superficially, appears no different from the first (rejected) project are not available to the public'. The following points are noteworthy: (a) if the earlier proposal could have been clinched, India would have been ahead of many countries in transgenic plant research, as contemporary knowledge and training in transgenic research would be fast forthcoming. (b) While the first field experiments on transgenic plants were carried out in USA in 1985, the *Bt*-cotton cultivars containing *Cry1Ac* gene were not yet approved in USA during the time when India was negotiating for procuring this technology. (c) Recombinant DNA technology applied to create transgenic plants in a wide range of cultivars, including cotton is not easy to master.

India has great skill in plant tissue culture and also has access to many transgenic constructs, with opportunities to transform the plant cells/calli into transgenic lines. Yet we have not been able to produce transgenic cotton lines, as the transformation of the transgenic cells of cotton into fully grown plants has not yet been possible.

- The field trials conducted during kharif 1998 at forty locations by MAHYCO on its *Bt*-cotton hybrids were in a total area of about 5.164 acres only. No plantation was carried out by MAHYCO prior to its obtaining an approval for the conduct of the trials. All trials were conducted in accordance with an approved site plan, plantation plan and plan for collecting relevant information on parameters that are required to be measured to assess the safety as well as utility of the transgenic cultivars. All information on plantation and on data collection is documented.
- The information furnished in table 2 of the paper is not only misleading but is also biased, without any scientific basis. The author claims that implications of use of the gene are prone to the evaluation of resistance. The author has not given either the LD_{95} values of any pest of *H. armigera* nor has she mentioned about the levels of expressions of Cry1Ac proteins in different plant parts. Without such information, how can one make assessment about emergence of resistance? The issue of development of resistance is a complex phenomenon and the minimum that is required to be known are the above. There is also a need to evolve a suitable IPM in order to enable the most effective use of transgenic *Bt* cultivars in the field and to evolve an agronomic practice suitable to a region in the context of target transgenic cultivars tested. This is a part of the evaluation strategies of the Government while conducting the biosafety evaluation. This part has not been appreciated by the author. Further, the extent of cross-pollination has also been a part of the evaluation process under practical conditions in the field. It is true that there will be seed setting by cross-pollination between the non-transgenic tetraploid compatible cultivars from the transgenic pollens of cotton in the adjacent cotton field. However, the implication of such cross-pollination needs to be understood. By providing a separation between the border rows of transgenic cultivars and the non-transgenic ones it will be possible to substantially trap the escape of transgenic pollens to an extent that may not be significant on any count. Such data are being generated through Indian trials.
- The statement of the author made in table 2 (p. 1071) that 'Regulatory process non-transparent' is not clear. She further states that there is 'Need for public information and vigilance'. The regulatory process is as transparent as it should be. All the contained open field experiments are documented with the map of a site plan, the planting pattern and the isolation distances. The protocols for conducting the experiments are approved by the Review Committee on Genetic Manipulation (RCGM). The applicant watches the experimental site. There is a full record of persons conducting the experiments. Any outsider willing to visit the experimental site is escorted to the site by the applicant or his nominee provided the person discloses his identity and the purpose of visit. Records are maintained about the persons visiting the experimental sites. Copies of the authorization letter embodying all these aspects are available with the District Collector of the State where the experiments are conducted. The State Government is fully kept informed about the experiments. In what way therefore, is the regulatory process non-transparent? In addition to the regulatory authorization for the conduct of such experiments, DBT has convened several public meetings and has given statements to the press about these experiments.
- The toxicity and allergenicity information on *Bt*-cotton was generated by MAHYCO on the basis of the directives of the RCGM as such information on ruminants (goat model) was not yet available anywhere in the world. Similarly, allergenicity information was also not available, but was generated in Brown Norway (BN) rats. The information so generated did not show any additional risks from the use of *Bt*-cotton compared to its non-*Bt* counterpart.
- The author has stated (p. 1074) that 'Recapitulating points made earlier in the paper: the protein coded by this gene' (*Cry1Ac*) 'is known to be most toxic to the tobacco budworm, which is not a major pest of cotton in India. In laboratory studies *H. armigera*, a major Indian pest, is known to be variably susceptible to Cry1Ac protein, and can very quickly evolve resistance under selection'. This point is admittedly a relevant one and therefore, Indian experiments include the elaboration of the LD_{95} values for different Indian *H. armigera* along with the levels of expression of Cry1Ac proteins at different cotton plant parts at different ages. Unless the target *Bt*-cotton plants consistently express Cry1Ac proteins well above the LD_{95} values, it would not be useful to introduce such cultivars in commercial agriculture. In addition, as stated earlier, sound IPM strategies would also be built in to delay the emergence of resistance in *H. armigera*. It is pointed out in this context that management of the menace of *H. armigera* costs the country close to Rs 1100 crores annually. Strategies to cut such costs can in no way be belittled and ridiculed.

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Response:

I thank Ghosh for clarifying aspects of the regulation of the *Bt*-cotton project. It was precisely because accurate information is not readily available to the public that I presented my own understanding as gleaned from 'mere' newspaper reports of regulatory issues, and it is good to have at least a partial straightening of the public record. However, I am disappointed in the lack of answers to many technical questions raised in the paper.

- *MAHYCO vs Monsanto*: Ghosh has clarified that the major reason for non-approval of the Monsanto project was due to financial aspects. According to him, approval of the Monsanto project would have enabled India to be 'ahead of many countries in transgenic plant research as contemporary knowledge and training in transgenic research could be fast forthcoming'. He points to the absence of transgenic cotton in India as indication of a deficiency in indigenous expertise to do this. Perhaps others could comment on this statement?
- *Information in table 2*: Ghosh states that the 'information' in table 2 is misleading 'without scientific basis'. The only 'information' there is under column I (features of the *Bt*-cotton project), the other two columns containing questions

raised on the basis of other studies (referred to in the text) regarding relative susceptibility of pests in the laboratory, field, etc. Since he questions just one of these features (regarding transparency of the regulatory process), it seems that his statement is biased.

- *Resistance management and other technical questions*: Ghosh responds to specific questions under columns II and III with general statements regarding the 'need to evolve a suitable IPM' (exactly, we would like to know details), 'implication of such cross-pollination needs to be understood', (exactly, what information do we have on this?) and so on. Other questions not answered: Are 1 acre tests too small? Are 1–2 seasons of testing too few? Are 2 years sufficient for backcrossing and testing?
- *Transparency of regulatory process*: Ghosh lists the procedural aspects that are open to the public. However, his statement that the process 'is as transparent as it should be', the lack of specific responses to specific questions, and his reading of my paper as belittling and ridiculing the *Bt*-cotton project, suggest that he has missed the spirit in which it was written. Much more discussion on the nature of transparency is required before the public can be confident of obtaining information that it is entitled to. Openness lies in the 'nitty-gritty'.

I hope that there will be more such discussion that would not only clarify misconceptions but also answer some of the questions raised here. Such a discussion would go a long way toward building the basis for a truly democratic process of decision making on this, and future, genetic engineering projects.

GEETA BHARATHAN

Bt-cotton: The view from MAHYCO

While Geeta Bharathan argues in her article that 'It is imperative that assessments of *Bt*-cotton project and future GE projects should be based on considerations in which the biological basis of the technology are clearly distinguished from societal issues', she herself has done precisely so in her article. Further, there are many factual errors in the article, which need to be pointed out. Also, the uncanny way in which issues like the terminator technology and farmer suicides have been mixed up with the technology and regulatory aspects of *Bt*-cotton obfuscates the truth that these are totally unrelated.

I would like to set the record straight on *Bt*-cotton so that readers, who have not had the opportunity to closely follow the developments of *Bt*-cotton in India, get the correct picture.

1. Transgenic cotton today is grown on over 5.3 million hectares (m ha), an increase of 43% over the 1999 area of 3.7 m ha in 6 countries around the world. These countries include USA, Australia, South Africa, Argentina, Mexico and China. China increased its genetically modified (GM) cotton area to more than 10% of its cotton area in 2000. The fact that millions of cotton farmers in both industrial and developing countries opted for *Bt*-cotton speaks volumes of the confidence and trust farmers have in its ability to help them tackle the bollworm problem[1,2]. In fact, the area planted with GM crops worldwide increased to 44.2 m ha; up from 39.9 m ha in 1999, an impressive increase by 11% (ref. 2).
2. India has the largest acreage of cotton in the world[3]. The major pests impacting cotton growers in the country are the bollworms, predominantly *Helicoverpa armigera*, for the control of which insecticides worth around Rs 1200 crores are used annually. In spite of this, farmers are suffering huge losses. Their yields have reduced, incomes have dropped and debts have increased[4].
3. MAHYCO began discussions with Monsanto for licensing *Bt* technology in 1993. An agreement was signed and MAHYCO then received from the Review Committee on Genetic Manipulation (RCGM) in Department of Biotechnology (DBT) permission to import the *Bt*-cottonseed in 1995. It imported 100 g of *Bt*-cotton seeds in 1996. These were used for backcrossing into elite Indian varieties by achieving 3 backcrosses in a calendar year in a glasshouse approved by DBT. Only such lines which were either commercially being used or are likely to be introduced in the near future were considered.

Between 1996 and 1998, according to the direction of RCGM, MAHYCO had carried out extensive tests in India, which included studies on outcrossing, germination, weediness, food/feed safety, allergenicity, toxicity, pollen escape, etc. These studies have established that *Bt*-cotton is safe.

In 1998, following permission by RCGM, the first multi-centric field trials were carried out on 40 locations in nine states in India. The data were submitted in February 1999 and reviewed and accepted by the RCGM.

The data from the 1999 trials were also submitted and reviewed by RCGM in April 2000. In May 2000, after reviewing the data on bio-safety and field trials, RCGM recommended that MAHYCO approach the Genetic Engineering Approval Committee (GEAC) for further action. In July 2000, GEAC permitted MAHYCO to conduct countrywide field trails on 85 ha and seed production on 150 ha. These are now in progress[5].

4. The Government of India has banned the entry of terminator technology (Office Memorandum No. 82-1/98 PQD, dated 25 May 1998 regarding strict watch on any likely import of seeds having terminator gene) and statements to this effect have been made in the Lok Sabha and Rajya Sabha. Monsanto was not involved with this technology. However, since they were unnecessarily implicated, they have made public commitments not to commercialize this technology, even if it becomes available. This was widely publicized and the author does not seem to be aware of it.
5. The choice of genes and resistance development: The author has made a point that *Cry1Ac* gene is not the most appropriate gene for controlling the target pest. We would like to state that the choice of *Cry1Ac* as the most appropriate gene, is based on extensive studies. We wish to inform the author that Australia also has *Cry1Ac* in their commercialized cotton and not *Cry1Ab* as mentioned by her. To date there has been no report of any scientific data to show that *Cry1Ab* is superior to *Cry1Ac* to control *H. armigera* as implied by the author.

Our own in-house studies conducted in India have clearly shown that *Bt*-cotton with *Cry1Ac* is quite effective against the major Indian bollworms, namely *H. armigera*, *Earis vittela* (*Earis insulana*) and *Pectinophora gossypiella*. These have been confirmed by other workers also[6]. The author herself has cited a publication which states that Cry1Ac protein was found to be the most potent one in a test of 11 different Cry proteins, followed by Cry1Aa and Cry1Ab (ref. 7).

Over the last 5 years, in spite of large-scale introduction of *Bt*-cotton in USA, no incidence of a minor pest becoming a major pest has been reported, not withstanding the keen scientific attention this technology has been receiving during this period.

6. There has been no sign of any bollworm species showing resistance to this transgenic crop. That has also been confirmed in a recent paper by Tabashinik *et al*.[8]. However pro-active measures have been taken in USA, in consultation with experts in academic institutions, to develop resistance management strategies which include deploying *Bt*-cotton as one of the major components of integrated pest management, refugia, gene pyramiding, optimum dosage, etc. These strategies will be appropriately modified to suit local conditions and will be extended in due course in India also, as it has been done in other countries where *Bt*-cotton has been commercialized.

7. Regulatory Process: All the data generated by MAHYCO have been submitted to RCGM and to GEAC. MAHYCO has followed all the guidelines prescribed by DBT over the last six years in developing *Bt*-cotton. The regulatory procedures are very stringent and no responsible agency will seek any short-cut methods as alleged by the author (see ref. 5 in her article).

Obtaining field permit involves obtaining approval from the respective state governments, where the experiments have to be conducted. The copy of the permit is sent to the Chief Secretary, District Collector and District Magistrate of the state where the experiment will be conducted.

8. Use of *Bt* spray vs *Bt*-cotton: *Bt* transgenic technology in cotton helps in overcoming certain limitations of *Bt* sprays such as the need for repeated applications, sensitivity to solar radiation, wash-off due to rain, etc. It is an acknowledged scientific fact that transgenic technology is an improvement over conventional spraying[9].

9. The author fears that the non *Bt*-cotton grown in plots adjacent to *Bt*-cotton will act as refugia and suffer more attacks by bollworms. Let it be known that the bollworm moths do not distinguish between *Bt* and non-*Bt* crops while laying eggs. Those laid on *Bt* plants get killed upon hatching owing to inherent insecticidal ability of these plants, while those laid on non-*Bt* plants may survive and cause damage if no control measures are taken. The situation is similar to any two plots grown with protection and without protection against pests. *Bt* crops do not encourage infestation on the adjacent normal crops. On the other hand, they enhance biological control, by allowing natural enemies of pests to survive due to drastic reduction in spraying of chemical pesticides to control bollworms. *Bt*-cotton could thus become a valuable component of integrated pest management[10,11].

10. Geeta Bharathan has also raised certain economic issues. We wish to inform the readers that *Bt*-cotton in USA and other countries has fetched both economical and ecological benefits to the farmers and therefore it is being increasingly grown.

Finally, we wish to mention that insect-resistant *Bt*-cotton introduced in 1996 in USA and thereafter in other countries is improving the comparative advantage through an increase in yield and reduction in costs of cotton production. It is also likely to further reduce the prices by 6%. Comparative advantage of Indian cotton assessed through Domestic Resource Cost Coefficient (DRC) suggests that in recent years, the comparative advantage is eroding due to lower productivity and declining international prices. *Bt*-cotton can provide 20% increase in productivity in India, thereby improving the DRC substantially[12].

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12. Naik, G., *Impact of Bollgard on Indian Cotton Sector*, Indian Institute of Management, Ahmedebad, 1999.

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Response:

Barwale's response will enable sober discussion of issues surrounding the *Bt*-cotton project itself. First, a clarification of the phrases '*Bt*-cotton case' and '*Bt*-cotton project'. The former includes the *Bt*-cotton project as well as factors ('terminator technology', socio-economic aspects of cotton farming in India) that led to the controversy. Second, I draw the attention of the readers to a thorough, technical review of issues pertaining to transgenics and pest management (Sharma, H. C. and Oritz, R., *Curr. Sci*., 2000, **79**, 421–437) that discusses, in general, many points that came up in my account of the *Bt*-cotton project.

Some of the points made by Barwale are matters of detail, not readily available to those not directly involved in this area of research (the reason why the questions originally were raised in my article). Therefore, I am thankful for his view of the history and background of the *Bt*-cotton project (his points 1, 2, 7), and for his corrections and clarifications of some questions raised in my paper (his points 5, 6, 9). Below are some comments on the last, further questions raised (addressed to both MAHYCO and regulatory agencies), and then some general comments (on his points 4, 5, 10).

It is reassuring to learn that (i) *Cry1Ac* is the best gene for Indian conditions (although Barwale does not give us citations for results from field studies); (ii) no minor pests became major ones in the US over a period of 5 years of *Bt*-cotton growing; (iii) there is no reason to expect that non *Bt*-cotton fields adjacent to *Bt*-cotton fields will suffer greater insect damage than normal; and (iv) extensive studies on pollen escape, outcrossing, germination, weediness, etc. have been conducted in India: Again, citations are not given for results from these studies. Further clarification on time taken for backcrossing is requested: Were the 3 backcrosses done using multiple molecular markers to select the desired genetic background? Unaddressed questions pertaining to the MAHYCO project include: Adequacy of 1 acre plots and 2 seasons at the stage of field trials. General points (not part of the *Bt*-cotton project) not discussed include the need to broaden the pool of genes as emphasized by Sharma and Oritz and, apparently, being pursued by ICAR scientists (*Businessline*, 10 April 1999; 11 February; 2000).

A major point of concern continues to be that of resistance management. It is true that resistance has not arisen as rapidly as anticipated in Arizona (USA), but that might only mean that the models used to predict early evolution of resistance were missing a critical parameter, not that resistance will not evolve in the insect pests in the near future (Tabashnik, B. E., pers. commun.). Therefore, while it is reassuring to hear that strategies for management are being planned '. . . appropriately modified to suit local conditions', it would be even more reassuring to hear some details: What are the elements of the management plan? Would it be essentially the same as those in the US and Australia? Are there enough background data to enable appropriate modification as proposed? Given Barwale's familiarity with difficulties in pest management, I am sure he can understand the anxiety of those who are familiar with the complexities of the issue, but not with the strategies planned to handle these complexities. For instance, Sharma and Oritz (*Curr. Sci.*, 2000, **79**, 421–437) suggest that variability of *CryIAc* gene expression may be the cause, for instance, of *Bt*-cotton failure in Australia. Should we also expect such failures under Indian conditions? How likely is it to occur? At a time when transparency is desirable, so as to separate the technological from the societal factors, it is very important that the former are clearly spelt out.

Since some of the societal issues in the problem of cotton farming in the past apparently come from inadequate pest management, anxiety on this point is not unreasonable. It would also be useful for the public to be informed as to which part of the regulatory process is responsible for overseeing the plans for management. Will it be the GEAC that will evaluate the current field trials? How detailed a management plan does it require? Who will be responsible for implementation?

My paper tried to use the *Bt*-cotton case as a point of reference in order to generate general public discussion on biotechnological applications in agriculture in India. In this context, I would like to clarify two points that appear to have been misunderstood by responses to the paper: One (as mentioned above), the '*Bt*-cotton case' includes the '*Bt*-cotton project'; therefore discussion of the former will necessarily include not only the latter, but also other factors. In trying to understand how public perception was piqued, moulded and distorted, we need to consider all factors that went into the process. If we want to clear up public (mis)understanding, then the technological and other aspects need to be discussed separately. Since I tried very hard to do this, I am puzzled as to how, exactly, my paper 'obfuscates the truth'. Two, the polarization I mention refers to differences in positions taken by the forces that oppose GM technology in the West (where the technology itself is of prime concern), and in countries like India (where intellectual property rights issues tend to be emphasized). Obviously, there is considerable support for the technology in both societies; understanding differences in the factors that move public perception must help in understanding where the overlap, if any, lies (A brief account of these aspects can be found at http://life.bio.sunysb.edu/ee/geeta/Bt-Cotton.htm). Discussion on all these issues needs to be kept alive so that decision making is fully transparent and in the interest of the public at large.

GEETA BHARATHAN

MEETING REPORTS

Recent trends in crystallography*

To commemorate the birth centenary of K. Banerjee, one of the pioneer crystallographers of India, a two-day symposium was organized at the Indian Association for the Cultivation of Science (IACS), Calcutta. The inaugural ceremony was attended by more than 200 participants, including J. R. Helliwell, University of Manchester and the Editor-in-Chief of *Acta Crystallographica*, special invitees, past students and family members of Banerjee. S. K. Sikka, Chairman of the Indian National Committee on Crystallography (BARC, Mumbai) inaugurated the symposium. In his Welcome Address, D. Mukherjee (Director, IACS) highlighted the role of crystallography in interdisciplinary research and mentioned the golden heritage of IACS marked by the contributions of C. V. Raman, M. N. Saha, K. S. Krishnan, K. Banerjee, S. Bhagavantam and many others. The Chairman of the Organizing Committee of SRTCRA 2000, and a member of the Commission on Powder Diffraction (CPD) of IUCr, S. P. Sengupta, pointed out the importance of holding the symposium in

*A report on the 'Symposium on recent trends in crystallography and its applications' (SRTCRA 2000) held at the Indian Association for the Cultivation of Science, Calcutta during 15–16 September 2000.