TRANSGENIC VARIETIES AND INDIA'S AGRICULTURE
Questions for Professor M. S. Swaminathan

***Review of Agrarian Studies*: Can transgenic varieties provide new – and hitherto unavailable – technological means to further increase agricultural productivity, enhance farmers' incomes and improve the crop composition of India's agriculture?**

M. S. Swaminathan: Transgenic varieties combine genes from totally unrelated species. For example, we can now transfer genes for salinity tolerance from mangroves to other species. Recombinant DNA technology is part of the evolution of genetics that started with the rediscovery of Mendel's Laws of Inheritance in 1900. In the early part of the last century, various techniques like irradiation, the use of chemical mutagens, and doubling chromosomes through colchicine treatment were adopted to develop novel genetic combinations. Today, such gene transfer can be done with ease through recombinant DNA technology. Both molecular marker-assisted breeding and gene transfer are now playing a very important role in developing novel genetic combinations to meet the challenges rising from biotic (i.e. pests and diseases) and abiotic (i.e. drought, flood, sea-level rise, etc.) stresses. They will gain further importance in the emerging era of climate change.

Priority should go towards solving those problems that cannot be solved with the currently available Mendelian technologies. For example, we need more climate-resilient varieties, such as wheat varieties tolerant to high night temperature, salinity- and drought-resistant plants, and plants resistant to new pests and diseases. Also, we should concentrate on the development of transgenic varieties rather than hybrids, since, in the case of hybrids, farmers will have to purchase seeds every year from the company. By contrast, they can keep their own seeds of transgenic varieties.

***Review of Agrarian Studies*: Do transgenic varieties pose any threat to biodiversity? What are the consequences of large-scale introduction of such varieties into actual cultivation?**

Professor Swaminathan: Transgenic varieties will not pose a threat to biodiversity, since the seeds can be kept by farmers. The threat comes from hybrids, whose seeds will have to be purchased every year by the farmer. Hybrids are those that exhibit hybrid vigour through a combination of two very different parents. They will not, however, breed true if grown again. Hybrids can be either conventional or transgenic. In crops like maize, hybrids are used extensively in view of the possibility of producing seeds economically.

The replacement of numerous local varieties with one or two hybrids will undermine the sustainability of production, since genetic homogeneity enhances genetic vulnerability to pests and diseases, as well as to abiotic stresses.

***Review of Agrarian Studies*: Do transgenic food crops pose hazards to human health?**

Professor Swaminathan: Transgenic food crops can cause harm to human health if they are not tested very carefully for biosafety aspects. In the USA, three different official agencies subject transgenic crops to thorough examination for their potential adverse impact on human health, biodiversity, and environment. These three agencies are: FDA (Food and Drug Administration), EPA (Environmental Protection Agency) and APHIS (Agricultural Plant Health Inspection Service). It is only after such thorough studies in government laboratories that clearance for large-scale cultivation is given.

***Review of Agrarian Studies*: Transgenic biotechnology represents the first great technological revolution in agriculture in which – at least in India – ownership, research, distribution, and utilization are controlled almost entirely by multinational corporations and the private sector. What are the consequences of this phenomenon for pro-people development?**

Professor Swaminathan: It is popularly said that the green revolution was a product of public sector enterprise, while the gene revolution is a result of private sector enterprise. The first is the result of public-good research, while the second is the result of commercial-profit research covered by intellectual property rights. What is therefore important is to step up public-good research in the field of biotechnology by supporting universities and government research institutions. Fortunately, in our country, there is a considerable amount of work in progress in public-good research institutions for making biotechnology a pro-small farmer development.

The important requirements for successful transgenic plant breeding involve issues of economics, ecology, ethics, and employment. In the field of economics, the cost, risk, and return structure will determine farmers' choice of technologies and decision in investment. In the case of ethics, it is important to ensure that all farmers, irrespective of the size of their holding and their risk-taking capacity, are enabled to derive advantage from new technologies. In the area of employment, it will be useful if women's Self-Help Groups are formed in villages to produce hybrid seeds. They can be given training in seed technology in Krishi Vigyan Kendras or other institutions where the pedagogic method is learning by doing.

***Review of Agrarian Studies*: Is India doing enough to make transgenic seed technology a public enterprise – and a public good?**

Professor Swaminathan: There is a considerable amount of work being done with support from the Department of Biotechnology of the Government of India. Other public-good institutions like ICAR, CSIR, and ICMR are also undertaking and supporting useful research in harnessing the power of recombinant DNA technology for addressing the issues of resource-poor farmers and consumers. We need to step up such work substantially.

***Review of Agrarian Studies*: Are the official mechanisms established in India to monitor and evaluate genetically modified organisms and biosafety adequate?**

Professor Swaminathan: Unfortunately, our official mechanisms are inadequate since they do not have their own testing facilities. I therefore recommended, in a report submitted to the Government in 2004, that "the bottom line of our national agricultural biotechnology policy should be the economic well-being of farm families, food security of the nation, health security of the consumer, biosecurity of agriculture and health, protection of the environment, and the security of national and international trade in farm commodities."

There is currently a move to establish a National Biotechnology Regulatory System through an Act of Parliament. The National Biotechnology Regulatory System should be capable of examining thoroughly the different aspects of biosafety and biosecurity. First, issues relating to the environment, including the impact on biodiversity, will have to be studied. Secondly, issues relating to the risks and benefits in terms of economics will have to be studied in a transparent and trustworthy manner. Finally, genetically modified plants should be subjected to evaluation from the point of view of their chronic effects. In the case of plants like brinjal, whose native home is India, every effort should be made to collect and conserve the native germplasm. All efforts in the area of introduction of new technologies should be based on the "four C" principle, that is, conservation, cultivation, consumption, and commerce.

***Review of Agrarian Studies*: Should Bt brinjal be banned?**

Professor Swaminathan: Bt brinjal need not be banned, but there should be caution that one or two hybrids do not replace hundreds of native varieties, all of which have distinct quality characters. India is the home of brinjal and we have rich genetic diversity in this crop. Steps should be taken to conserve this wonderful gene pool.

Also, studies should be carried out on the chronic effects of consuming Bt brinjal throughout one's life.

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COMMENTS

David A. Andow

Transgenesis provides new opportunities for crop improvement, but careful planning is needed to ensure that it will lead to increased agricultural productivity and enhanced farmer incomes in India. As Dr Swaminathan has emphasized, India should prioritize the development of varieties that farmers can save, instead of hybrid varieties, which require farmers to purchase seed from seed companies every year.

The strategy of using transgenesis to address problems that cannot be solved with the currently available Mendelian technologies may be a good one. However, Mendelian technologies are improving every year, and the number of problems that cannot be addressed by Mendelian technologies is shrinking. For example, transgenic crop varieties tolerant to high night temperature, high soil salinity, and drought are being promoted strongly at this time. However, there remain significant physiological limits to what can be accomplished. Wheat can be made to be more drought-tolerant, but it is unlikely to become as drought-tolerant as barley, and it is highly unlikely to be able to grow in brackish water, as mangrove is. Indeed, as the physiology of drought tolerance is improved, site-directed mutagenesis (not a transgenic technology) coupled with marker-assisted selection may become more powerful than transgenesis in increasing physiological tolerance in plants. The large Danish grass seed company, DLF-Trifolium (which is a farmer-owned company), uses transgenesis to identify genes and alleles with valuable properties, but then uses high-throughput germplasm screening and marker-assisted selection to create the varieties with the desired properties, completely circumventing the need for commercial transgenic grass varieties.

All crop varieties pose some threat to biodiversity, which is related in part to the novelty of the new gene combination. There are several issues that should be evaluated: gene flow, effects on species and ecosystem processes, and evolutionary effects (NRC 2002). Gene flow can threaten native germplasm, change indigenous crop varieties, affect export markets, create super-weeds, and endanger plant species. Soil fertility, endangered species, pollination, secondary crop pests, honey production, silk production, etc., may be adversely affected. Resistance evolution to either a transgenic insecticidal toxin or a herbicide can also adversely affect crop productivity. The possibilities should be evaluated prior to commercialization by competent authorities in India. On the basis of my evaluation of India's assessment of biodiversity risks for hybrid Bt brinjal (Andow 2010), the Indian Government needs to improve the present evaluation system to make better-informed decisions about the potential effects on biological diversity.

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REFERENCES

Andow, D. A. (2010), *Bt Brinjal: The Scope and Adequacy of the GEAC Environmental Risk Assessment,* Sunray Harvesters, New Delhi, downloaded from www.biosafety-info.net/file_dir/383642714cb3fcfce2ee7.pdf on 28 March 2011.

NRC (National Research Council) (2002), *Environmental Effects of Transgenic Plants: The Scope and Adequacy of Regulation,* National Academy Press, Washington, D. C.

Ronald J. Herring

Dr Swaminathan's interview reflects an emerging consensus on transgenic crops: all cultivars are genetically modified, but transgenic techniques offer unique potential in many circumstances. Disaggregation is important. A trait that reduces demand for labour, however bred into the plant, may be less desirable in specific cultivars and labour markets, for example, than an insect-resistant trait. India has experience with two of the latter: Bt cotton and Bt brinjal (*baingan*, aubergine, eggplant, *Solanum melongena).*

Cotton and brinjal jointly constitute a puzzle. The same transgene [cry1Ac], producing the same insecticidal protein, in the same regulatory system produced very different outcomes. Bt cotton has done well in agro-economic and environmental terms; Bt brinjal in field trials offered even greater benefits to farmers in net income and pesticide reduction, but failed to receive regulatory clearance.

The rationale for transgenic brinjal is that recombinant DNA techniques could introduce a trait – insect resistance – that is absent in the genome. India's biosafety system normalizes every technique of genetic modification Dr Swaminathan mentions *except* rDNA. Transgenic brinjal was subjected to special regulation solely because of the means of modification that introduced the trait. In politics, rDNA plants have been successfully constructed as uniquely risky plants: "GMOs". Biosafety regimes in many countries make this strong assumption. Assuming risky plants, control seems imminently reasonable, but is extraordinarily difficult to operationalize or administer. Biosafety regimes introduce, but only pretend to solve, the Goldilocks paradox: regulation should be not too little, not too much, but just right. If too little, a real hazard might result. If too much, unintended economic and political consequences could follow. Strict biosafety regulation favours multinational life-science firms comfortable with regulation that suppresses local competition. Bt cotton offers one example: the only monopoly Mahyco-Monsanto ever had was one conferred by official regulation in New Delhi. Politically, biosafety institutions disproportionately empower small numbers with appropriate cultural capital, skills, and connections – typically not farmers.

Democracy must then ask of biosafety regulators: do transgenic plants produce more hazards than cultivars bred by other means? The European Commission Directorate-General for Research recently answered the question in a publication entitled "A Decade of EU-funded GMO Research (2001–2010)":

> The main conclusion to be drawn from the efforts of more than 130 research projects, covering a period of more than 25 years of research, and involving more than 500 independent research groups, is that biotechnology, and in particular GMOs, are not per se more risky than e.g. conventional plant breeding technologies. (*Ibid.*, p. 16)

Similar conclusions flow from a meta-analysis by Ricroch, Bergé, and Kuntz (2011). Finding evidence of some hazard unique to transgenic plants, as opposed to plants bred otherwise, is easy in political discourse and administrative law, but not in peer-reviewed science. Mutagenic plants, for example, seem somewhat riskier than transgenic plants (Batista *et al.* 2008), but are not subjected to special scrutiny in India, Europe, or the US. India has 259 registered mutagenic cultivars, none of which went through the Genetic Engineering Approval/Appraisal Committee. One is a brinjal, *Dehra Dun local*, transformed by gamma radiation for solasodine production, introduced in 1975. It is one of five mutagenic eggplants in the world in the registry of the International Atomic Energy Agency; the other four are in Italy.[1] Had the Bt trait that produced volatile politics in 2009–10 resulted from bombarding brinjal's genetic material with gamma radiation, rather than insertion of a single gene from a soil bacterium widely used in organic biopesticides, it would not have faced the bar of biosafety regulation at all: no GEAC, no Minister Ramesh. Bt proteins may present some hazard, but no biosafety testing anywhere has been able to find evidence. Only one claim was publicly cited for raising the bar for Bt brinjal, but Professor Séralini's method was dismissed by the GMO Panel of the European Food Safety Authority.

1 Registered with the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, and FAO/IAEA Agriculture and Biotechnology Laboratory, Seibersdorf, of the International Atomic Energy Agency, Vienna.

The property-like rights granted by biosafety regulation to Mahyco-Monsanto's Bt cotton hybrids did not arise in Bt brinjal. More open-pollinated varieties (OPVs) from the public sector than hybrids from the private sector were planned for release. Public institutions developed locally popular varieties with the insect-resistant gene donated by Mahyco. The Tamil Nadu Agricultural University developed four Bt brinjal varieties; the University of Agricultural Sciences, Dharwad, six; the Indian Institute for Vegetable Research developed Bt brinjals as well. Mahyco planned to concentrate on hybrids, assuming that many farmers would eventually switch to hybrids for yield advantage. Farmers would have been able to choose between two types of insect-resistant cultivars: lower-cost varieties with saveable seeds, and higher-yielding, more expensive hybrid seeds. These arrangements were noticeably absent from the political discourse at all levels.

The politics of rDNA brinjal reflected a common urban bias: farmers receive lagged and uncertain access to products of the genomics revolution taken for granted by urban populations via biotech products in industry, medicine, and pharmaceuticals (Herring 2008). Bt brinjal faced a biosafety burden of proof that, in strict construction, is impossible to meet. The Government of Kerala requested a moratorium for at least 50 years until complete safety is proven. By that standard, the peanut could not be approved for cultivation. Branded as GMO, Bt brinjal resurrected newly effective political forces that had been sidelined by wholesale farmer acceptance of Bt cotton. One effect was to discourage public sector scientists, who Dr Swaminathan rightly sees as the best hope for progress in transgenic crops in India. Were brinjal farmers not so few, small-scale, unorganized, and politically powerless, they might have succeeded in contesting biosafety claims for rejecting Bt. Were rDNA plants not subject to unique regulation, brinjal farmers' lack of political capacity would not have mattered.

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REFERENCES

Batista, Rita et al. (2008), "Microarray Analyses Reveal that Plant Mutagenesis May Induce More Transcriptomic Changes than Transgene Insertion," *Proceedings of the National Academy of Sciences,* 105, 9, pp. 3640–45.

Herring, Ronald (2008), "Opposition to Transgenic Technologies: Ideology, Interests, and Collective Action Frames," *Nature Reviews Genetics London,* 9, Nature Publishing Group.

Ricroch, A. E., Bergé, J. B., and Kuntz, M. (2011), "Evaluation of Genetically Engineered Crops Using Transcriptomic, Proteomic and Metabolomic Profiling Techniques," *Plant Physiology,* February, pp. 111.173609.

K. R. Kranthi

Genetic modification of crops will certainly assist farmers in the near future to move away from chemical-intensive agriculture. Investment in public sector research for the discovery of new genes that confer economically important traits for resistance to biotic and abiotic stress will pave the way towards developing transgenic varieties that can be provided to farmers at low cost, and also ensure establishment of self-reliant agriculture.

Dr Swaminathan's response to the question whether the official mechanisms established in India to monitor and evaluate genetically modified organisms and biosafety are adequate – "our official mechanisms are inadequate since they do not have their own testing facilities" – is extremely important. It is ironical that though 90 per cent of biosafety and 100 per cent of agronomic evaluation experiments, and all other ecological and laboratory assessment studies that are prerequisites for environmental release and approval, are carried out only by ICAR institutions, the final decisions on biosafety clearance, and commercial approval of hybrids and varieties, are made by two bodies: the GEAC, which is a part of the Ministry of Environment, Government of India, and the RCGM, which is a part of the DBT under the Ministry of Science. Though all the experiments on GM crops are conducted by ICAR/NARS, these institutions have had very little influence on the final approval of GM varieties and hybrids. The RCGM and GEAC continue to control the regulatory process of approving specific GM hybrids or varieties despite their limited knowledge and understanding of agricultural sciences, though based on data generated by ICAR/NARS institutions. Even now, it is not too late to establish the requisite testing facilities under the appropriate Ministries.

1 The Ministry of Science and Technology, through the RCGM, should create institutional facilities at a single institution under the CSIR, to examine the claims made by the technology developers related to the "trans-gene event and molecular characteristics" of the GM organism at the "containment" stage.
2 The Ministry of Environment and Forests, through the GEAC, should create facilities at a single institution for all short-term and long-term biosafety studies related to the environment, effects on micro-organisms, animal, and human health at the "confined" evaluation stage.
3 Once the transgene event is declared as biosafe for environmental release, the different GM varieties and hybrids containing the approved transgene should be tested by the respective crop institution and the AICRP of ICAR/NARS for agronomic/economic advantages and trait efficacy in different agro-ecological conditions, to facilitate notification by the Ministry of Agriculture of the GM crop variety/hybrid for commercial cultivation.

4 Post-release monitoring for seed purity compliance monitoring, and any possible declining efficacy and ecological impact of the trait, should lie with the ICAR, while biosafety monitoring and assessment of environmental effects should be the responsibility of the institution set up by the GEAC.
5 If the NBRA comes into effect, it should establish a 'National Institute for GM Product Biosafety Assessment and Compliance' that can operate as a single-window system to examine, ascertain, verify, and subject all proposed GM material to complete biosafety assessment in a reliable and transparent manner. The process will simplify and expedite GM crop use through expert assessment. The relevant ICAR/NARS institutions can evaluate the GM crops for trait-effectiveness, agronomy, and economic benefits before the GM varieties/hybrids are notified for cultivation.

Dr Swaminathan stresses the need for transgenic varieties in preference to hybrids. The experience with Bt cotton in India clearly shows that Bt cotton hybrids have spread rapidly in a short span of time, to occupy an area of more than 92 per cent of the total cotton acreage. These have thus replaced the popular varieties of cotton that were developed by public sector plant breeders over the last 60–70 years, and which had been occupying at least 60–65 per cent of the area under cotton before the introduction of Bt cotton. The species *Gossypium arboreum* and *Gossypium herbaceum*, which have their evolutionary origins in India, together occupied about 25 per cent of cotton acreage before 2002; they are now confined to small patches of land which account for less than 1 per cent of the area under cotton in India. Farmers do not prefer the conventional varieties any longer because of the peer pressure related to the lure of Bt cotton hybrids in the market. It has become very difficult to obtain seeds of *G. hirsutum* or any of the Desi varieties in the market, or even from public sector institutions.

Transgenic varieties confer several advantages. Apart from enabling farmers to preserve and reuse the seeds, the straight varieties perform better with reference to the transgene trait due to the stable "homozygous" condition, in comparison to the segregating trait in bolls of F-1 hybrids due to the "hemizygous" state. Twelve countries other than India have been cultivating Bt varieties and have been harvesting much higher yields (more than 1,000 kilograms of lint per hectare) compared to India (about 500 kilograms of lint per hectare), where only Bt hybrids are cultivated. Hybrid seed production is tedious, labour-intensive, and expensive. It does not lend sustainability and stability to farming systems. Moreover, in producing more bolls per plant, hybrids make use of more fertilizer and water, produce more vegetation, and deplete more nutrients from soils, apart from requiring more insecticide for protection against sap-sucking pests. Conventional varieties, especially the Desi species, are innately more tolerant to moisture stress, drought, disease, and pests, and therefore need less input of fertilizers and insecticides. The yield of Bt hybrids has been stagnant at an average of 500 kilograms of lint per hectare for the last five years, and is unlikely to increase. Increasing plant population above the national average of 10,000 plants per hectare is not possible with hybrids due to the high seed cost. The global average population of varieties is 1,10,000 plants per hectare, and many countries are raising their yields by increasing the population of their compact varieties. Reducing the costs of cultivation would be possible only by reverting to varieties of appropriate architecture that suit the varied agro-eco regions and diverse soil types of India. Varieties, not hybrids, can strengthen genetic diversity and lead to long-term sustainability.

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ABBREVIATIONS

AICRP	All-India Coordinated Research Project
CSIR	Council of Scientific and Industrial Research
DBT	Department of Biotechnology
GEAC	Genetic Engineering Approval Committee
GM	Genetically modified
ICAR	Indian Council of Agricultural Research
NARS	National Agricultural Research System
NBRA	National Biotechnology Regulatory Authority
RCGM	Review Committee on Genetic Manipulation

Suman Sahai

1. Dr Swaminathan rightly points to the potential of marker-aided selection (MAS) for breeding crops with desirable traits. MAS accompanied by conventional breeding can combine the search for valuable genes with tried and tested breeding technologies to develop crop varieties, bypassing the biosafety concerns raised by genetic engineering. In my view, the technologies of the future are MAS and Apomixis. The latter is a nascent and developing technology that would enable the 'freezing' of hybrid plants with their combination of favourable traits in such a way that it can become true breeding. Apomixis is a process that would allow hybrids to breed true so that farmers can save the seeds for replanting.

Although transgenic technology, theoretically, offers the potential to create crops with new combinations of genes, its application is likely to be restricted by the drawbacks of the technology itself. Paramount among these is the question of biosafety, resulting from the entirely unpredictable changes that can happen when 'foreign' genes are inserted in unknown numbers and from unknown locations into chromosomes in a host cell. The high level of uncertainty associated with genetic engineering makes it difficult to ensure effective biosafety testing. Several things can happen in a cell when it is genetically engineered, and we do not always know what these are. Neither do we always know how cell metabolism is affected, what new proteins are synthesized, or which of the new proteins are safe and which dangerous. This makes safety testing a difficult process because, "if you don't know what to test for, what do you test?"

An important point has been raised about varieties versus hybrids. In India, all transgenic crops are being produced as hybrids rather than as varieties. There is no justification for this since hybrids do not offer any advantage here. In this case, hybrids function as proxy Intellectual Property Rights (IPR) by not allowing the farmer to save seed and forcing him to return to the seed company to purchase seed. The Bt hybrids that are being developed do not offer any advantage to the Indian farmer. In the US and in China, several of the Bt cottons are developed as true breeding varieties, not as hybrids. Despite the demand that transgenics should be produced as varieties, the Indian government has refused to intervene at the policy level.

2. Transgenic crops pose a threat to biodiversity in several ways. The best understood of these threats is posed by cross-pollination. When foreign genes like those that confer herbicide tolerance (HT) shift to natural populations as a result of cross-pollination, the biodiversity of those populations can come under threat. For instance, planting herbicide-tolerant rice has resulted in the HT trait shifting to red rice, a relative of cultivated rice and a weed, making red rice a much more persistent weed and hard to eradicate. Similarly, selective advantage has been conferred on other weed plants due to gene transfer. Countries that are centres of origin of major crop plants do not allow the planting of genetically modified versions of those crops because they are afraid of the impact of foreign genes on their crop biodiversity. For this reason, China does not permit the cultivation of GM soyabean, Mexico does not allow GM corn, and Peru does not allow GM potato. India is the only country that is going ahead with GM rice despite it being the centre of origin of rice.

In a study published in *Nature* in the late 1990s, it was shown that the toxic exudates from Bt corn roots negatively impacted soil micro-organisms and damaged the microbial diversity of soil. Constant exposure of pests to Bt toxin from Bt cotton has led to their developing resistance, as well as to the emergence of secondary pests. All this affects biodiversity and its equilibrium in a given ecosystem.

3. Several studies have shown that transgenic crops can have damaging effects on human and animal health. Adverse health effects of GM crops can result from over-expression of an existing protein or other toxicologically active substance, or from

the expression of totally new substances. These would not be found in the natural plant species, but could be seen in the plant from which the foreign gene came. New, potentially dangerous proteins could also result from new products synthesized by metabolic pathways that are altered after the introgression of foreign genes. Once genes foreign to the host genome are put into the cell, they would get inserted into the host DNA randomly. This could change the code sequence of the DNA in that region, resulting in the synthesis of new proteins. Such proteins need not all be dangerous, but there is a good possibility of there being some that are either toxic or with disease-inducing properties.

Where the new protein is known, testing can be done, but problems arise when the toxicological hazard results from a pleiotropic response, and involves multiple changes in either protein or metabolic constituents which cannot be predicted. In such cases, testing is not possible and the hazardous elements can remain undetected. Adequate and sensitive testing procedures for allergenicity do not exist, especially in India. This means that animals and humans could be exposed to undetected allergens. Before any further commercialization is allowed, testing procedures of sufficiently stringent standards should be put in place.

There are studies showing that rats fed on a diet of GM corn revealed severe organ damage. They developed lesions in the kidneys and liver, and they had compromised immune systems. Other studies on rats fed with GM potato showed similar organ malformation and altered immune response. There are several reports of stomach lesions in rats, false pregnancies in cows, uncontrolled cell growth, and damage to the animal immune system, following feeding studies conducted with GM foods. When the first GM tomato, "Flavr Savr," was fed to rats in 1994, many of them developed lesions in the stomach, and 7 out of 40 rats died within two weeks.

4. When a technology is controlled by the private sector, especially by transnational companies, there is usually a lack of transparency. Hence, both the agenda and the safety of the technology and its products become questionable. Worse, these companies have a commitment to creating private goods to maximize profits and to keep their shareholders happy, and not to creating public goods that are needed by developing societies like India. The drive to create IPR-protected private goods tends to ignore the needs of the poor. That is why India's first GM crop is cotton, which is a commercial crop. Over 300 Bt cotton hybrids have been officially released in India, all of them by the private sector and not the public sector, and all of them as hybrids so that the farmers cannot save seed. GM technology in India has focused disproportionately on the Bt gene that is owned by Monsanto and which earns that company big money in license fees every time it is used. Pro-poor needs in agriculture are not addressed by such companies in their choice of either crops or traits.

5. India could do much more to make transgenic technology a public good. Public sector institutions here are chasing the Bt gene and working to create hybrids, and violating biosafety guidelines, just like the private companies. They must develop greater confidence and stop imitating the private companies if they are to have any relevance. Currently, their track record is not good.

6. The regulatory system in India is in dire need of a thorough overhaul. Gene Campaign had filed a writ petition in the Supreme Court in 2004, asking for a radically improved regulatory system. That has not yet happened. The system currently in place lacks technical competence, does not include the public as required by the Biosafety Protocol, and is not transparent. It is riddled by conflict of interests, with the same people putting in applications for approval and occupying positions on the decision-making bodies.

7. Bt brinjal or any other GM crop should not be given permission for commercial release in India until we have a demonstrably improved regulatory system, and testing procedures capable of ensuring the biosafety of transgenic crops and foods. That is not the case today.

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S. Ramachandran Pillai

I am in broad agreement with the views expressed by Dr M. S. Swaminathan in his answers to the questions raised by the *Review of Agrarian Studies*. His lucid, straightforward, and sharp answers will certainly help clarify many of the doubts that members of the public have about the use of transgenic varieties. Groups in Europe that are opposed to genetically modified crops use the biosafety argument as a protectionist measure to keep non-European products out of their markets. Their influence and propaganda, and that of multinational corporations in the United States that produce transgenic crops, are creating much confusion in the minds of people in India on the subject of the use of transgenic varieties.

I argue strongly that India should make use of advances in science and technology to increase agricultural production. This is necessary to improve the living conditions of the peasantry and agricultural workers, and also for the overall development of the Indian economy. Agriculture is increasingly becoming an unviable venture for vast sections of the Indian peasantry, particularly the poor among them. Transgenic varieties can, I believe, help these sections come out of their present difficulties.

As correctly pointed out by Dr Swaminathan, both molecular marker-assisted breeding and gene transfer are now playing a very important role in developing novel genetic combinations to meet the challenges arising from biotic and abiotic stresses. The need to meet such challenges is all the more important in the context of climate change. As recommended by the National Farmers Commission, priority should be given in genetic modification to the incorporation of genes that can help impart resistance to drought, salinity, and other stresses. Water-use efficiency as well as improvement of nutritive and processing qualities should be accorded priority in the agenda of agricultural research.

While using transgenic varieties, rigorous biosafety tests should be conducted to examine the potential adverse impact on human health, biodiversity, and the environment. Dr Swaminathan has pointed out that three agencies – the Food and Drug Administration, the Environmental Protection Agency, and the *Animal and Plant Health Inspection Service* – are working to examine these issues in the United States. Similar institutional arrangements are necessary in India, where the present arrangements for testing and monitoring are totally inadequate, and also, perhaps, incompetent.

There is widespread anxiety among the general public about the risks of transgenic technology. In view of this, it is important that all information and data relating to field trials and safety assessments are in the public domain. The functioning of the Genetic Engineering Approval Committee (GEAC) of the Government of India should be made more transparent. It appears that, at present, field trials and safety assessment studies are being conducted mainly by the developers themselves. The present system needs a thorough change. We have also learned from the experience of cultivating Bt cotton that there is an important gap in our knowledge with regard to the cultivation of transgenic varieties. Detailed economic evaluations are necessary when a transgenic variety is introduced.

A mechanism must be established to fix seed prices, and to ensure accountability in cases of crop losses due to the failure of seeds.

While using transgenic varieties and hybrids, appropriate measures should be taken to establish and maintain comprehensive seed banks to conserve genetic resources.

The use of new technology must not lead to global multinational companies controlling Indian agriculture. The cases of Bt cotton and now Bt brinjal pose a further threat: that of all future seeds coming under the control of global multinational companies and, consequently, of farmers being charged extortionate prices for seeds. Multinational companies use biotechnology not for the long-term benefit of agriculture or the peasantry, but in order to make short-term profits. As the profit motive is the driving force of the private sector, companies may ignore safety measures, and fail to harness the pro-poor features of biotechnology in order to find solutions to the problems of food insecurity, malnutrition, poverty, unemployment, and backwardness.

Although it is necessary, for the above reasons, for the public sector to play the leading role in the development of biotechnology, the Government of India is not giving adequate importance to the development of biotechnology in the public sector. Unfortunately, now that the Indian Council of Agricultural Research and the Indian Agricultural Research Institute are functioning like junior partners of Monsanto, and given the current cooperation agreements between India and the United States, the research agenda of Indian agriculture is becoming more and more the agenda of multinational corporations. The policy direction and attitude of the Central Government in this regard need radically to be changed.

The proposed National Biotechnology Regulatory System is inadequate and suffers from many infirmities. It should be made broad-based and democratic by involving scientists, social scientists, and representatives of peasant organizations. Since agriculture is a State subject in India, the States should also be represented adequately.

With regard to Bt brinjal, approval should not be given without public scrutiny of the data considered by the GEAC. Public access to information on trials of genetically modified crops must be ensured to ensure adherence to safety requirements. Transparency in decision-making is also necessary to avoid malpractices in the process of granting approvals.

I believe strongly that studies should be carried out on the long-term effects of consuming Bt brinjal throughout one's life. This is also necessary in the case of all crops used for consumption by animals.

S. Ramachandran Pillai is President of the All-India Kisan Sabha, the all-India peasant union that has more than 210 lakh members.

RESPONSE TO THE SYMPOSIUM

M. S. Swaminathan

This topic has aroused great interest and several valuable comments.

Dr David A. Andow has rightly pointed out that Mendelian technologies are improving every year. As a result, the number of problems that cannot be addressed by Mendelian technologies is shrinking. This is particularly true if we include molecular markers-based breeding. What is important is to ensure that research priorities are tailored to the needs of small farmers and nature conservation. An important issue in relation to traditional methods of agriculture and biotechnology is the possibility of the coexistence of biotech and organic farming. The United States Secretary of Agriculture, Mr Tom Vilsack, has been advocating such coexistence. This will require very detailed knowledge about the extent of gene flow in nature (see *Science*, Vol. 332, 8 April 2011, pp. 166–69).

Ronald Herring has concluded that there is so far no evidence of GM technologies being more risky than conventional plant-breeding methods. He has therefore stressed the need for a more rational approach to assess the risks and benefits associated with transgenic crops and varieties. Many of the public concerns can be met satisfactorily only by establishing a regulatory mechanism that inspires public, political, professional, and media confidence. I hope the proposed National Biotechnology Regulatory Authority Bill, to be considered by the Parliament of India, will ensure that the regulatory systems have adequate facilities for independent verification of the data presented by breeding companies or breeders.

Mr S. Ramachandran Pillai has rightly emphasized the need to take the benefits of modern science to small and marginal farmers. In order to insulate small and marginal farmers from the risks associated with higher input costs, particularly seed, it will be useful to establish either an insurance system or a liability fund. A Committee on Agricultural Biotechnology that I chaired in 2003–04 had recommended that small farmers who buy costly seeds of GM crops should be given insurance policies by the concerned companies. A liability fund could also be designed, particularly to deal with cases of gene flow from GM to organically grown crops. This will help compensate organic farmers who are not able to get the needed certification because of genetic contamination.

Dr K. R. Kranthi has rightly emphasized the need for independent testing facilities, both with reference to biosafety and field performance. It will be useful for the ICAR to establish a designated All-India Coordinated Research Project on GM varieties. Dr Kranthi has also stressed the need to avoid genetic erosion as a result of the spread of one or two cotton hybrids over large areas. For example, the species *Gossypium arboreum* and *Gossypium herbaceum*, which have their evolutionary origins in India and which formerly occupied 25 per cent of total cotton acreage, are now facing the threat of extinction. It is therefore necessary that biotechnology, biodiversity, and business become mutually reinforcing and not antagonistic.

This series of interventions has helped to highlight the many dimensions of the problems relating to transgenic varieties. Indian agriculture needs the best available technologies in order to improve the productivity and profitability of small holdings in an environmentally sustainable and socially equitable manner. We therefore need better methods of assessment of risks and benefits.