In this issue

Transgenic crops

A major achievement of the twentieth century has been an increase in crop productivity through conventional breeding methodologies. The Green Revolution in the late sixties and the early seventies brought about a dramatic increase in the productivity of wheat and rice through the deployment of dwarf varieties. Hybrid maize, and towards the end of the twentieth century, hybrid rice are other examples. Since the 1950s, major breakthroughs have been achieved in understanding the molecular basis of life so much so, that at the beginning of the new millennium, we have almost the entire DNA sequence information on two flowering plants, *Arabidopsis* and rice, the former being a model weed and the latter, one of the most important cereal crops of the world. The sequencing of these genomes has utilized a whole gamut of technologies developed since the 1970s – recombinant DNA techniques, vectors, sequencing methodologies, high throughput instrumentation and computational analysis of large sets of data. Unlike in animal systems where pluripotent somatic cells have been difficult to find, in plants the totipotency of somatic cells has been known since the late sixties. This property, coupled with the discovery of molecular mechanisms of crow gall disease, in which a bacterium introduces a part of its DNA into the plant somatic cells, has led to the development of techniques for the introduction of foreign DNA into most of the crop plants. Genes and genetic information can be mobilized from one to the other organism, thus widening the scope of genetic exchange far beyond what sexual reproduction generally allows. This is the essence of transgenic technologies.

Many see transgenic technologies as a great opportunity to enhance productivity and concomitantly increase the sustainability of agriculture. Many others see it as a dangerous development which has implications for human health, biodiversity, sustainable development and the economic well-being of small farmers.

Technologies and their use can only be assessed in a social context. While the articles explaining the progress of the scientific developments and their use in developing transgenics assess technological developments in the field and their potential use, policy-related articles help us relate technologies to social needs and, therefore, may lead us toward developing a more rational perspective on transgenic crops. Thirteen articles in this special issue, besides summarizing the state of research and development of transgenic crops, assess many of the policy issues related to Indian agriculture and deployment of transgenics in the field. In the first article 'Agricultural biotechnology research in India: Status and policies', Sharma *et al.* (**page 297**) outline the contributions made by the Department of Biotechnology (DBT) in promoting research and development in the area of crop biotechnology and in establishing regulatory regimes for evaluation and release of transgenic crops. The article spells out financial support provided from public funding to plant biotechnology, current work being done with assistance from DBT and other agencies in various public-funded laboratories and key areas of research that have been identified for research support in the Tenth Five Year Plan (2002–2007). Besides this, the article also provides information on the regulatory regimes that have been set up to monitor the development and field deployment of transgenic crops. A list of transgenics that are being developed by the private sector and are at various stages of clearance for field application is also provided. As would be seen, most of these transgenics have been developed by crossing exotic transgenic lines with breeding lines developed in India. Very little gene discovery is being done by the private sector in India.

In the second article 'Global review of commercialized transgenic crops: 2001' James (**page 303**) provides a worldwide overview of the deployment of transgenic crops. The global area under transgenic crops has steadily increased in both developed and developing countries. However, the spread of transgenics is uneven. USA and Argentina alone account for 90% of the total area under transgenics in 2001. Transgenics have been mainly deployed in soybean, corn, cotton and rapeseed 'Canola' with other crops having a very minor presence on the transgenic scene. Only two traits, herbicide resistance and insect resistance, have been deployed extensively. How is it that while in the laboratories a large number of transgenics have been developed – very few are in the field? James does not particularly address this question but ends his article on an optimistic note that many new and novel products will become available for commercialization by the year 2005. The author sees a major contribution from transgenics in conjunction with conventional breeding in developing more productive and sustainable agriculture.

A brief article put together by Grover and Pental (**page 310**), 'Breeding objectives and requirements for producing transgenics for major field crops of India' is based on a survey conducted amongst plant breeders, pathologists and entomologists on problems that affect the yield potential of major Indian field crops. The article could not have been put together without the enthusiastic participation of agricultural scientists and coordinators for different crops in the ICAR system. The questionnaire sent to scientists asked for information on breeding priorities at the national and regional level for various crops and also for comments on the need for transgenics for hybrid seed production, nutritional enhancement, resistance to biotic and abiotic stresses and herbicide resistance. The survey shows that a major emphasis needs to be placed upon resistance to diseases and pests for stabilization of yield. For yield enhancement, heterosis breeding in some of the crops is recommended. Nutritional enhancement gets a positive mention in some crops but resistance to herbicides receives a low response. It is hoped that this article will set the stage for prioritizing the research agenda for crop improvement through the use of both conventional and transgenic approaches to breeding.

Worldwide, transgenics are being developed for a number of traits, namely, (a) resistance to herbicides, (b) pollination control mechanisms, (c) insect resistance (genes from bacteria and plants), (d) virus resistance through pathogen-derived sequences, (e) resistance to fungi through antifungal proteins or R genes, (f) nutritional improvement, (g) senescence retardation, (h) resistance to abiotic stresses and (i) for production of valuable pharmaceuticals and secondary metabolites. The next five articles in the special section discuss the status of research and development in the above areas with particular emphasis on biotic and abiotic stresses.

The major area of development of transgenics for resistance to insect pests has been dealt with by Ranjekar *et al.* in the article 'Genetic engineering of crop plants for insect resistance'. The authors describe (**page 321**) the major pests of Indian crops and evaluate different strategies including use of *cry* genes from *Bacillus thuringiensis*, *vip* genes from Bt, antifeedant proteins of plant origin, etc. for engineering crops for resistance to insect pests. Two insect resistant crops with *cry* genes, namely Bt corn and Bt cotton, are already released for commercial cultivation in many countries. A major concern is the management of resistance as insects are notorious for developing resistance to insecticidal molecules. This issue has also been discussed in the article with a recommendation for diversifying the gene sources for proper resistance management.

The survey conducted and reported in the article 'Breeding objectives and requirements for producing transgenics for major field crops of India' has clearly shown that fungal diseases are a major cause of yield losses. Grover and Gowthaman (**page 330**) in 'Strategies for development of fungus-resistant transgenic plants' describe various gene-based strategies for breeding disease-resistant plants. The strategies can be broadly divided into two categories, development of transgenics with genes encoding antifungal proteins or metabolites and development of transgenics with *R* genes which work through the induction of a hypersensitive response. Success with the use of antifungal molecules has been below expectation. A more effective strategy would be to use *R* genes. With more and more knowledge accumulating on the structure, function and evolution of *R* genes, it should be possible to mine alleles (genes) for resistance from related but otherwise sexually incompatible plants and deploy these into crops. From the standpoint of Indian agriculture, mining of genes conferring resistance to diseases and pests from wild relatives and transferring these to crop plants through transgenic technologies could be the most useful and pertinent area of research and development.

As a country with lot of area under tropical and sub-tropical climatic conditions, insect pressures on our crops are high. Some of these insects, for example, whitefly, are notorious carriers of gemini viruses. Dasgupta *et al.* in their article 'Genetic engineering for virus resistance' describe (**page 341**) some of the major viral diseases in our field and commercial crops. The list is long and breeding for resistance through conventional methods is difficult. Pathogen-derived resistance, as demonstrated first by the introduction of coat protein sequence of tobacco mosaic virus in tobacco, is a method of great interest for breeding resistant plants through transgenic approaches. Various pathogen-derived sequences used for genetic transformation of crops have been described. The phenomenon of post-transcriptional gene silencing (PTGS) has a major role to play in developing transgenics for virus resistance. The authors have discussed PTGS approaches, the use of *R* genes and some other non-pathogen derived resistance based strategies for developing virus-resistant crops. The authors have emphasized large-scale diversity analysis of viruses causing major diseases so that more durable strategies for resistance could be developed.

In an extensive article on abiotic stresses 'Addressing abiotic stresses in agriculture through transgenic technology', Grover *et al.* (**page 355**) have reviewed research being carried out worldwide and in India on transgenics for resistance to abiotic stresses like heat, drought and waterlogging. The article contains a very informative table on different transgenics that are being tested for resistance to abiotic stresses. In genetic studies, resistance towards abiotic stresses observed amongst cultivar/races of a crop species follows the inheritance pattern of quantitative traits. However, genetic transformation experiments, increasing the expression of a putative stress-resistance conferring gene by using constitutive high expression promoters, seems to confer significant levels of resistance. This contradiction can be only resolved by large-scale field testing of the transgenics. The authors describe some of the work underway in laboratories in India and call for more involved research in the area of abiotic stresses in India.

The articles on specific areas of interest in genetic manipulation are followed by a general article on genetic transformation of crops. The article 'The current status of plant transformation technologies', by Veluthambi *et al.* (**page 368**) discusses the developments that have taken place in the area of genetic transformation of crop plants. They describe the science behind the transformation methodologies, their relative application on different crops and vectors used for transformation. One major concern with transgenic crops has been the presence of antibiotic resistance conferring genes along with the genes of agronomic interest. The antibiotic resistance conferring genes are used to allow selection of transformed tissues *in vitro*. The authors discuss the technologies that are now available for the removal of undesirable marker genes from transgenic plants. These technologies should take care of the widespread fear of the presence of antibiotic resistance conferring genes in the food chain. Gene silencing at the transcriptional or post-transcriptional levels have emerged as an important research area. Gene silencing in transgenics was first reported from plants and has now been shown to work in a wide variety of organisms. Gene silencing has implications for developing methodologies for pathogen-derived resistance and for gene stacking (insertion of multiple genes as crop plants require breeding for many traits). The authors end their article with a brief review of transgenic work underway in different laboratories in India.

The yield of grain legume crops must improve to allow more widespread cultivation of these environment-friendly and protein-rich crops. To date, routine genetic transformation methodologies have been established only for rice, cotton, mustard (and other related *Brassica* species), potato and tomato in India. For many cereals like maize and wheat, routine high throughput protocols are not available. Although some success has been reported, reproducible protocols for transformation of grain legumes and many oilseed crops are not available. In an article 'Regeneration and genetic transformation of grain legumes: An overview', Chandra and Pental discuss (**page 381**) the difficulties with genetic transformation of leguminous crops. Except herbicide-resistant soybean, which was developed through a rather inefficient method of particle gun bombardment (or biolistics), no other legume transgenics are currently in the field. The authors suggest that if problems of grain legumes have to be dealt with, efficient protocols for genetic transformation would have to be developed.

A general article by Chand and Pal 'Policy and technological options to deal with India's food surpluses and shortages' (**page 388**) looks into a whole gamut of questions and policy structures bedevilling agricultural productivity and diversification in the country. The importance of transgenics for Indian agriculture can be only understood in the context of an overall assessment of food requirements. The authors critically assess the demand models and project that while in the coming years cereal production requires an increase of 1.88% per annum, production of pulses, edible oils, milk, fruit and vegetable require annual growth rates of around 3%. The yields of rice and wheat have plateaued out since the early 1990s, while productivity of pulses and oilseeds has stagnated for almost the last thirty years. Therefore, major technological innovations will be required to increase the productivity of our major field crops, particularly of oilseeds and pulses, which have, otherwise, low input requirements. Besides technological breakthroughs in breeding, imaginative economic policies will have to be pursued to utilize food surpluses, to encourage crop diversification and to achieve nutritional security. The authors suggest that subsidies to agriculture, which are currently very high for cereal crops, need to be phased out and non-cereal crops need to be encouraged by both economic policies and by breeding and genetic engineering interventions.

All transgenics will have to go through very extensive nutritional, and wherever necessary, toxicological studies. These will also have to be tested for yield in replicated trials. Who will bring quality seed of transgenic material to the market? Clearly the seed industry. The seed industry has a stake in transgenics. Most of the plant breeding work, due to policy shifts in the developed countries, has moved into the hands of transnationals. These on their own or in collaboration with Indian industry have been and in future would be likely to put their proprietary genes into Indian varieties. As a consequence, industry has high stakes in the development and deployment of transgenics. In the article 'The Indian seed industry: Its history, current status and future', Gadwal (**page 399**) writes on the current status of Indian seed industry and need for transgenics and provides suggestions for faster clearance of transgenic material. His article shows that the ratio of saved seed to bought seed has remained ten to one from 1990 to 1999. Seed industry will have to grow by leaps to provide all the seed requirement of the farmers. Will the small farmers of India be able to afford the seed produced by huge conglomerates? Can the Indian seed industry withstand competition from transnationals? Some of these questions have been raised and discussed in this study.

Sahai (**page 407**) writes about 'India's plant variety protection and the Farmers Rights Act, 2001'. This act will allow breeder's rights for the first time in India. However, the act allows farmers to keep their own seed and also to exchange it at the community level. Under the TRIPS agreement, India had a commitment to establish a *sui generis* (self generating) system for providing effective Plant Breeders Rights. In advanced countries, UPOV (Union for the Protection of New Plant Varieties) has framed Plant Variety Protection guidelines (in 1972, 1978, the latest being in 1991) to protect rights of breeders on plant varieties. Sahai draws out salient points in India's PVP act and suggests some changes to make it more farmer-friendly but rejects attempts to bring in UPOV as it does not fulfil the needs of Indian farmers at this juncture.

In the last article 'Transgenics for productive and sustainable agriculture: Some considerations for the development of a policy frameworks', Pental (**page 413**) makes some policy recommendations on the areas covered in this issue and some of the areas related to transgenics which have not got adequate coverage. The thrust of the recommendations is that Indian agriculture requires input of transgenic technologies both for enhancing productivity and sustainability of agriculture. Crop diversification and rotation is essential both for meeting nutritional requirements and for sustainability of agriculture. A strong public research system is essential but spending more money without organizational changes will not help. The author argues that the biggest impediment to use of transgenics is the current IPR regimes prevailing in the developed countries which are slowly being imposed upon developing countries. So far in India we have resisted the temptation of patenting gene sequences and transgenics, we should continue to do so, but this freedom is not being used effectively by the public/private sector in India to develop useful material for farmers. As a policy, India should try to protect the agricultural need of developing countries by rejecting overzealous patenting and by crusading for strengthening of the CGIAR institutes which have served the cause of agriculture in both developed and developing nations so effectively in the twentieth century. The breeding goals emerging from the survey (Grover and Pental in this issue) should serve as a focal point for planning the research agenda in the Tenth Plan and beyond. Biotic stresses and heterosis breeding deserve maximum attention.

Improvement of Indian agriculture will require substantial inputs from diverse areas – infrastructure development, effective water management, diversification of crops, conventional breeding and transgenic technologies. It is very clear that in the absence of judicious policies, clear research objectives, multidisciplinary research efforts and adequate funding, efficient and timely deployment of transgenics through public system will remain a mirage. The articles in this special section, we hope, will initiate a major discussion on the formulation of a research agenda for agriculture in the next fifteen to twenty years and clearly identify a few areas of transgenic research which would be funded and organized in a proper manner so that some of the transgenic technologies can be put at the service of farming communities.

We would like to thank a number of people who helped with the organization of this special section. All the authors deserve our thanks for their patience and enthusiasm. Most of the technology-related articles have been put together by some of the most active workers on transgenic crops in India. The policy-related articles, we hope, would interest readers of *Current Science* as technologies have to be related to social and economic necessities. We thank G. S. Bhalla, M. Bharathi, Atika Chandra, Bharat Chattoo, Indranil Dasgupta, P. K. Jaiwal, M. V. Rajam, H. S. Savithri, R. P. Sharma, S. K. Sinha, S. K. Sopory, V. Udayasuriyan, Anupam Varma and K. Veluthambi, for reviewing the articles. Many others who helped have been acknowledged in the respective articles. Sangeeta Agarwal and Suchi Sood helped with drawings of some of the figures. Christel R. Devadawson and Arun Jagannath deserve thanks for the final editing of the manuscripts.

Anil Grover
Deepak Pental