Future of Plant Science

Indian plant biology enters the biotechnology era

Nandula Raghuram

India is endowed with 47 000 known species of plants and at least two-thirds as many scientists working on plants. Experimental plant research in India is almost a century old, and traditional knowledge has existed in the Indian civilization for well over two millennia. Today, Indian plant biology research is spread across nearly 200 universities, including 31 fully fledged agricultural universities, >90 research institutes and centres, and a few private foundations and companies. Research in these organizations is almost entirely funded by the government through various agencies such as the Indian Council of Agricultural Research (ICAR), Dept of Science and Technology (DST), Dept of Biotechnology (DBT), Council of Scientific and Industrial Research (CSIR), Dept of Atomic Energy (DAE), University Grants Commission (UGC) and, to some extent, the Ministry of Environment and Forests. India currently spends ~0.1% of its gross national product (GNP) and 15.0% of its total research and development (R&D) expenditure on agricultural research and plant biology.

Since the mid-1960s, when the 'GREEN REVOLUTION' (see Glossary) was launched in India to boost crop production with the help of high-yielding varieties, fertilizers and irrigation schemes, Indian agricultural scientists have developed >2300 high-yielding varieties and hybrids. These varieties played a major role in doubling food-grain production (especially wheat and rice) without using additional land. India was the first country to produce hybrids of several crop varieties. Today, India is the world's largest producer of fruits, spices and condiments, and the second largest producer of vegetables [1]. Agriculture constitutes up to 28% of the Indian economy and 15% of exports. Tissue culture is another area of strength in applied plant biology that has brought tremendous economic benefits using a range of crop plants, medicinal plants, horticultural varieties and forest species. Recently, the Micropropagation Technology Park at the National Chemical Laboratory, Pune, has transferred the technology for micropropagation of teak trees (*Chlorophora excelsa*) to International Plant Laboratories (Glastonbury, UK). This is perhaps the first plant biology example of technology transfer from India to a Western country.

There has been considerable expansion in the institutional infrastructure for modern plant biology. For example, several Centres for Plant Molecular Biology (CPMB) have been established in the past decade, one of which has been upgraded recently into an autonomous National Centre for Plant Genome Research (NCPGR) in New Delhi. Plant molecular biology is also one of the major components at the International Centre for Genetic Engineering and Biotechnology, New Delhi. In addition, three National Gene Banks have been established for germplasm conservation. Of these, the one located at the National Bureau of Plant Genetic Resources, New Delhi, has been recently modernized and upgraded to a capacity of 1 million accessions, making it the largest gene bank in the world. It has already secured 7100 accessions of underused crops, among others. See Ref. [2] for a history of plant molecular biology in India.

Recent trends

Some interesting new trends have been emerging on the Indian plant biology scene over the past few years. Convergence is the first and the most visible trend among them. Indian plant biologists are increasingly making their presence felt in the 'mainstream' life sciences community, and are benefiting from, as well as contributing actively to the growing convergence in all areas of modern biology.

'…the Micropropagation Technology Park at the National Chemical Laboratory, Pune, has transferred the technology for micropropagation of teak trees (*Chlorophora excelsa*) to International Plant Laboratories, UK.'

This has meant, among other things, a significant increase in the number of multidisciplinary collaborative projects being carried out in the country. Networking is another major trend, which is reflected by the rapid increase in the number of multi-institutional research projects. For example, an ongoing programme of bio-prospecting for biological wealth in India involves collaboration between 15 institutions across the country, including the Union ministry's Dept of Space, the Indian Institute of Remote Sensing (Dehradun) and the Botanical Survey of India (Pune), as well as several universities, research institutes and two non-governmental organizations. This project involves landscape and biodiversity characterization using remote sensing and bio-monitoring techniques, as well as traditional taxonomy, genetic characterization of plant varieties by finger printing, and gene and biomolecule prospecting. Another such project relates to molecular taxonomy, involving at least 12 institutions, with at least one taxonomist and one molecular biologist from each of them. The third important trend is to go green – research areas such as green pesticides, biocontrol, biofertilizers, crop rotation and multicropping, herbal drugs, bioremediation, agroforestry, biodiversity identification and conservation and rural employment generation now take centre stage in modern plant biology, as much as molecular biology or biotechnology do. Plant scientists are also beginning to tap Indian strengths in information technology and emerging capabilities in bioinformatics, albeit slowly.

 1360-1385/02/$ – see front matter PII: S1360-1385(01)02214-2

Glossary

Convention on biological diversity (CBD): An international agreement signed under the United Nations Environment Programme at the 1992 Earth Summit held in Rio de Janeiro, Brazil. The Convention (http://www.biodiv.org/) established three main goals: the conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of the benefits. Since this convention brought biological resources under the control of national governments for the first time, bioresources are no longer common property of mankind. CBD also provides a framework to prevent external exploitation of bioresources or indigenous knowledge, with regard to their use by foreign countries, without prior informed consent and benefit sharing.

DXP pathway: A chloroplast-based alternative pathway for terpenoid synthesis was discovered a few years ago in bacteria and plants, which leads to the formation of isopentenyl diphosphate and dimethylallyl diphosphate, the two basic precursors of isoprenoids from pyruvate via 1-deoxy-D-xylulose-5-phosphate (DXP) [a]. It had been thought that these precursors were synthesized exclusively in the cytosol by the well known mevalonate pathway. Research on this new pathway, which is unique to bacteria and plants, could provide the basis for the development of new antibiotics, herbicides and antimalarials.

Green revolution: The term popularly used to describe the dramatic increase in food-grain production in India since the mid-1960s following the introduction of high-yielding, dwarf and hybrid varieties along with fertilizers, pesticides, tractors, harvestors and improved irrigation. In recent years, environmental awareness has led to the quest for more sustainable farming technologies, especially to reduce the dependence on chemicals and energy derived from fossil fuels.

WTO and IPR: The establishment of the World Trade Organization (WTO) (http://www.wto.org/) in 1995 to oversee multilateral trade was a culmination of the Uruguay round of negotiations to revise the General Agreement on Tariffs and Trade (GATT), a multilateral trade agreement. Agricultural products became part of the scope of responsibilities of GATT for the first time during the Uruguay round, which prevents member countries from using import barriers (tariffs) or providing high subsidies to protect domestic agriculture from foreign competition. Similarly, intellectual property rights (IPR), such as patents (including patenting life forms), copyrights and trademarks, were brought under GATT for the first time, to homogenize IPR policies of the member countries in line with the policies prevalent in the USA, and to prevent the national governments from using IPR regimes to protect domestic industry from foreign competition. Developing countries view CBD as supportive and WTO as contrary to their interests.

Reference

a Eisenreich, W. *et al.* (2001) Deoxyxylulose phosphate pathway to terpenoids. *Trends Plant Sci.* 6, 78–84

Plant biotechnology

During the past five years, there has been a rapid growth in plant biotechnology R&D in India. For example, several laboratories have acquired or developed the skills for raising transgenics in Indian crop plants, including those for which transformation and regeneration protocols were not available. The biopesticidal genes from *Bacillus thuringiensis* (*Bt*) have been transferred into pigeonpea (*Cajanus cajan*), brinjal (*Solanum melanogena*), tomato, potato, rice, sorghum, cauliflower, cabbage, mustard and chickpea (*Cicer arietinum*), and are at different stages of testing. Efforts are also on to identify other endotoxins to combat resistance to the commonly used cry1 endotoxin from *B. thuringiensis*. Some groups have identified promoters for developing tissue-specific expression systems in crop plants, whereas others have been targeting the transgenes into chloroplasts to achieve higher expression levels. Scientists from the University of Delhi and Indian Agricultural Research Institute have been sequencing a part of chromosome 11 in rice under the international rice genome project, and NCPGR has initiated the genomics of the indigenous chickpea. There are some groups working on the manipulation of fatty acid content in oil crops, or improving protein content in rice and potato by transgenic methods, and others have been working on delaying fruit ripening in tomato and banana using antisense technology. Although transgenic varieties have yet to be cultivated on a commercial scale, hopefully these efforts should produce various transgenic plant varieties in government-funded laboratories and provide them at affordable costs to the farmers, helping to prevent private-sector monopolies.

Another major area of ongoing research is the search for genes responsible for biotic and abiotic stress resistance by using molecular markers, and the transfer of these genes into various crop cultivars. Several groups have begun working on these aspects in the past few years across the country, with some success. Similarly, major multidisciplinary and multi-institutional collaborative projects have been initiated recently, which will screen all the important medicinal and aromatic plants of India for compounds of pharmaceutical and agricultural relevance, and convert them into patentable products. These programmes owe their origins, at least partially, to the US patents relating to neem, turmeric and other plant-based products that have been used in traditional Indian medicine and agriculture for centuries. These controversial patents granted to foreigners have provoked an urgency in India to tap the biodiversity and indigenous knowledge for new products and biomolecules of pharmaceutical and agricultural importance. In addition to these initiatives by the government, several Indian pharmaceutical firms have also begun screening for plant-based bioactive molecules.

Future directions

The future R&D agenda recommended by various major funding agencies focuses on biotic and abiotic stress, input-use efficiency, bio-prospecting and plant-based bio-actives. Although research on green manures, biofertilizers and biopesticides will remain important, the National Academy of Agricultural Sciences (NAAS) acknowledges that these biological alternatives can at best supplement chemical fertilizers and pesticides, but cannot replace them completely in India. The Academy also strongly endorses the role of biotechnology and genetic engineering in crop improvement, along with conventional breeding techniques [1]. According to the DBT Review Committee on Genetic Manipulation, initial results on transgenic crops indicate substantial agronomic benefits, and field trials for many others are in progress*. The areas recommended by DST for basic research include: plant abiotic and biotic stress, photosynthesis and crop productivity, ion transport, senescence and post-harvest physiology, signal transduction, reproductive biology, apomixis, seed biology, cell-cycle control, cell–cell communication, ecology, biodiversity and conservation, biological crop protection, cytology and molecular cytogenetics, tissue culture and differentiation, and biology of extremophilic organisms.

Gap areas

There are gap areas in Indian plant biology that do not feature in the future research agenda of any of the above agencies. For example, much work is needed on plant biochemistry and metabolism, especially metabolic regulation and assimilate partitioning. This would be particularly helpful in metabolic engineering for the next generation of plant transgenics. Similarly, the discovery of the DXP PATHWAY of terpenoid biosynthesis in plant chloroplasts has opened up a range of new possibilities for both basic and applied research in plant

*Annual Report (2000) Dept of Biotechnology, Government of India, New Delhi, India.

secondary metabolites [3], but this area is not being pursued actively in India at present. Secondary metabolism is also relevant because of the current focus on plant-based bioactives. India has a rich diversity of medicinal and aromatic plants; most of the active compounds in herbal drugs are likely to be secondary metabolites. One of the areas that has not received the research attention it deserves in India, in spite of some recent advances elsewhere, is enhancement of fertilizer-use efficiency (particularly of nitrogen), even though it is considered an important area of research. Among the advanced technologies, microarrays and proteomics are still in their infancy and are yet to be applied in Indian plant biology research.

Funding

Support from multiple funding agencies of the government (DST, DBT, CSIR, ICAR) has helped maintain some diversity and vibrancy, which might not have been possible under a single structure. The past decade has witnessed a rapid expansion of modern plant biology research in India, in spite of the stagnation of government support for R&D as a consequence of the structural adjustment and liberalization of the Indian economy. Notwithstanding the advantages of multidisciplinary and multi-institutional collaborations and focused applied research, they can also be viewed as cost-cutting measures. Considering India's large plant diversity, the potential of which is largely untapped, and the availability of skilled manpower, there is a strong case for greater support for basic research in plant biology. *Arabidopsis* provides one of the best examples of the applied impact of basic research. Research on other plants unique to India could also have unforeseen benefits, and the CONVENTION ON BIOLOGICAL DIVERSITY (http://www.biodiv.org/) provides a framework for protecting them from external exploitation, provided they are identified and tapped indigenously. Therefore, India has every reason to invest heavily in plant research and work towards becoming one of the world leaders in plant biology in the future.

Although there has been some discussion regarding enhancing private-sector participation in agricultural research, there are also concerns over the possible emergence of private monopolies for certain crops or technologies. There are several private seed firms in India that breed and sell seeds, and some of them also have ambitious R&D programmes. But it is the entry of large multinational corporations with broad patents in GM technologies that has raised concerns and protests by farmers' organizations (http://www.gatt.org/), especially since the WTO regime (http://www.wto.org/) brought Indian agriculture under intellectual property rights (IPR) for the first time. Fortunately, efforts are being made to master new technologies within government-funded laboratories, so that risks of monopolies can be averted, and the new technologies can be made available to the farmers at affordable prices. But an inability to sustain financial support could defeat this purpose, and give a handle to the critics of biotechnology who easily confuse the technology issues with issues of ownership, equity and access. The new Director General of ICAR, Panjab Singh, in his first public statements after assuming office recently, argued in favour of a stronger role for the public sector in Indian agriculture, and government support for research to the tune of 1.0% of the agricultural gross domestic product (GDP). The current level of government support is ~0.3% of the agricultural GDP, which is much lower than even the developing countries' average of 0.5%.

Therefore, government and public sector involvement in research and technology development will continue to be necessary for addressing the national needs, as well as for balancing public interest with private monopoly. In fact, India could provide an alternative model to the world through 'public' biotechnology.

Public policy

In terms of public perception and policy perspective, Indian plant biotechnology stands somewhere between the US and European extremes – the no holds barred, whole-hog approach of the USA, and the anti-biotechnology wave sweeping Europe. Being a late entrant, India also has the advantage of learning from the experiences of both these extremes, to adopt an appropriate mix that suits its needs and resources. In spite of the increasing influence of environmental movements, which predominantly have European affiliations (with due regard to them), there is no reason to believe that there is a strong public consensus, let alone unanimity, on issues related to plant biotechnology and GM foods in India. Fortunately, to date, the debate has remained among the directly involved parties, that is, environmentalists, farmers' organizations, scientists, companies, policy analysts and government. The media have also been fairly neutral in this debate, which allows space for informed and constructive dialogue between various stakeholders. The Indian plant biology community, and the policy makers guided by them, seem to believe firmly that transgenic methods will provide the best means to achieve maximum gains in the minimum time. However, the government recently refused clearance to introduce *Bt*-cotton developed by Monsanto (St Louis, MO, USA) for commercial cultivation in India, in spite of the recommendation by the DBT-monitoring committee that the field trials were satisfactory. This was apparently because agricultural scientists from the ICAR pointed out that the pest resistance was checked at a time when the pest load was not at its peak, and insisted that the trials be repeated under the supervision of agricultural scientists. The trials are currently being repeated and depending on the results, a decision is expected this year. But GM or no GM, Indian agricultural scientists, with government support, seem to be confident of meeting the food demands for the next few decades, by an appropriate mix of loss-prevention and yield-enhancement strategies. In conclusion, India has built a firm foundation for a bright future for plant biology and biotechnology and is determined to defeat Lester Brown's and Hal Kane's dismal predictions [4] for India in the 21st century.

Acknowledgements

I thank the Indian National Science Academy, New Delhi and the Royal Society, London, for a visiting fellowship to the UK, which gave me the necessary break to work on this long-pending article.

References

1 Katyal, J.C. *et al.* (2000) *Agricultural Scientists' Perception on Indian Agriculture: Scene, Scenario and Vision*, National Academy of Agricultural Sciences, New Delhi, India
2 Sopory, S.K. and Maheswari, S. (2001) Plant molecular biology in India. The beginnings. *Curr. Sci.* 80, 270–279
3 Eisenreich, W. *et al.* (2001) Deoxyxylulose phosphate pathway to terpenoids. *Trends Plant Sci.* 6, 78–84
4 Brown, L. and Kane H. (1994) *Full House: Reassessing the Earth's Population Carrying Capacity*, The World Watch Environment Alert Series, W.W. Norton & Co, New York, NY, USA

Nandula Raghuram
Dept of Life Sciences, University of Mumbai, Vidyanagari, Mumbai – 400098, India.
e-mail: raghuram98@hotmail.com