J. X. Kasperson and R. W. Kates, (eds.), 1990. Overcoming Hunger in the 1990s, a special issue of Food Policy, Vol.15, No. 4, pp.273-368.

Trying technology

Neither sure nor soon

Ellen Messer and Peter Heywood

New agricultural biotechnologies, in contrast to green revolution technologies, offer new tools and institutional frameworks to address agricultural and hunger problems in both well-endowed and marginal areas; in both the industrialized and the developing world. Developing nations, bilateral and international donors, and numerous non-governmental and private-sector participants contemplate a variety of environmental and economic, as well as cultural and nutritional, issues in choosing technologies. A review of the current state of plant biotechnologies, the crop plants and characteristics towards which they are aimed, and the institutional frameworks developing to implement them suggests that impacts on hunger will be minimal in the 1990s, but that institutional developments in the 1990s will probably shape their impact on hunger over the longer term.

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[1]E.C. Stakman, P. Mangelsdorf and R. Bradfield, *Campaigns Against Hunger*, Belknap Press of Harvard University, Cambridge, MA, USA, 1967; R. Barker and R.W. Herdt, *The Rice Economy of Asia*, Resources for the Future, Washington, DC, USA, 1985.

[2]J.R. Anderson, R.W. Herdt and G.M. Scobie, *Science and Food: The CGIAR and Its Partners*, World Bank, Washington, DC, USA, 1988.

[3]M. Lipton and R. Longhurst, *Modern Varieties: International Agricultural Research and the Poor*, World Bank CGIAR Study Paper No 2, World Bank, Washington, DC, USA, 1985; P. Timmer, *Getting Prices Right*, Cornell University Press,

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Over the past 40 years biological and social scientists, with the support of national governments and international donors, have been conducting 'campaigns against hunger'.[1] The results of their efforts are claimed to have kept half a billion people from starving[2] by reducing the incidence of famine among chronically food-short nations and also lowering the costs of staple foods for the poor.[3] Nevertheless, an estimated billion people still go hungry,[4] with 1–3 billion more hungry projected for the middle of the next century if current trends continue.

Emerging agricultural biotechnologies (ABTs) promise to reduce hunger by (1) increasing food production, (2) lowering food production and consumption costs, and (3) developing products to meet the special needs of nutritionally deprived groups.[5] In addition, biotechnological transformations in medical diagnostics and treatments and industrial employment and trade might also beneficially influence the nutritional, income and food situation of the hungry.

As critics are quick to point out, however, the choices to promote particular technologies, crops and crop characteristics, and the institutional contexts in which they proceed, might further imperil the food and nutritional plight of the poor, powerless and hungry.[6] On the basis of past technological and socioeconomic trends, they argue that ABT, like other technical advances, will compromise further the competitive positions of poorer farmers and nations, and increase the marginality of the rural poor. Nevertheless, most international donor organizations are scrambling to invest in ABTs for the improvement of agriculture in developing countries.[7]

Both proponents and opponents anticipate that ABT will change plants, agronomic methods, processing procedures, and ultimately the shape of rural, industrial and dietary life. At present those undertaking 'impact' and 'feasibility' studies in multiple areas of the world are presenting many scenarios of technology development. But clearly alternative futures, depending on what technological paths less developed countries (LDCs) choose and the institutional environment that shapes or facilitates those choices, are possible.

Some indications of the potential impacts of ABTs on hunger emerge by comparing the advances of these new technologies and institutions over the previous green revolution (GR) technologies and institutions

0306-9192/90/040336-10

and the ways in which the GR and ABT have approached choices in crops and crop characteristics. Additionally, we will consider how these new plant ABTs might affect possibilities to end hunger in the 1990s and subsequently.

Green revolution

The green revolution was launched in Mexico in the 1940s, with the stated purpose of ending and preventing hunger among the rapidly growing populations of the developing world. Responding to the Malthusian spectre that exponential growth in populations would outstrip arithmetical growth in food supplies, US scientists and policy planners, with the cooperation of the governments of the LDCs, embarked on a scientific–technological quest to bring the benefits of modern plant breeding and agronomy to LDCs and thereby increase food production. Efforts aimed to increase production in the most favoured agricultural regions, but it was anticipated that benefits would 'trickle down' to the poor. An additional aim was to bring modern agricultural science and technical research capacity to LDCs so that they might then take responsibility for feeding their own populations.

Over the next 20 years breakthroughs in conventional breeding resulted in potentially high-yielding varieties of wheat and rice, which were highly responsive to moisture and fertilizer and might produce many times the yields of conventional varieties under ideal agronomic conditions. These modern varieties were short and stiff-strawed so that the plants would not fall over under the weight of the extra grain. They were also insensitive to seasonal day length, thereby allowing for double- or triple-cropping in the best-irrigated areas. Under conditions of adequate and controlled moisture, fertilizer and pesticides and multiple cropping, these new seed and technology packages over the subsequent 20 years helped produce millions of extra tons of grain that enabled global food supply to keep up with population growth, although clearly Asia and Latin America benefited disproportionately more than Africa.

Nevertheless, these new varieties and technology packages that achieved their stated goals of producing piles of grain to feed the hungry had several shortcomings. First, their dedication to the most fertile, and usually irrigated, areas – a logical target for programmes designed to produce more food – effectively excluded the poorer farmers on more marginal, non-irrigated lands. Second, the widespread distribution of a few elite varieties, continuous monocropping, plus heavy applications of pesticides, depleted the genetic range of sown varieties of cereal grains and left large agricultural zones highly vulnerable to pathogens, pests and deteriorating soil and moisture conditions. Thus these technologies have demanded constant maintenance to assure stable yields in the face of increased vulnerability to pests and environmental degradation.

Successes of the GR have largely been limited to improvement in the yields of rice and wheat, where GR varieties now account for the varieties sown on one-third of the land allocated to those grains. Success has also been limited mainly to those farmers who control the best-irrigated lands and can afford the full package of productive factors. Efforts have been made to develop varieties that do well and do not mine soil nutrients under less than optimal fertilizer and moisture conditions. Modern variety maintenance and improvement have also

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Ithaca, NY, USA, 1986. See also P. Pinstrup-Andersen and P. Hazell, 'The impact of the green revolution and prospects for the future', *Food Reviews International*, Vol 1, 1985, pp 1–25, and E. Wolf, *Beyond the Green Revolution: New Approaches for Third World Agriculture*, Worldwatch Paper No 73, Worldwatch Institute, Washington, DC, USA, 1986.

[4]World Hunger Program, Brown University, *The Hunger Report: 1988*, Alan Shawn Feinstein World Hunger Program, Brown University, Providence, RI, USA, 1988.

[5]E, Messer and P. Heywood, 'Hunger and the "green-gene" revolution', in *The Future of Hunger*, Occasional Papers 88 (1), Alan Shawn Feinstein World Hunger Program, Brown University, Providence, RI, USA, 1988.

[6]See, for example, F.H. Buttel, M. Kenney and J. Kloppenburg, 'From Green Revolution to biorevolution: some observations on the changing technological bases of economic transformation in the Third World', *Economic Development and Cultural Change*, Vol 34, 1985, pp 13–55; H. Hobbelink, *New Hope or False Promise? Biotechnology and Third World Agriculture*, International Coalition for Development Action, Brussels, Belgium, 1987; C. Fowler, E. Lachkovic, P. Mooney and H. Shand, 'The laws of life: another development and the new biotechnologies', *Development Dialogue*, No 1–2, 1988; C. Juma, *The Gene Hunters*, Zed Press, London, UK, 1989.

[7]G. Persley, ed, *Agricultural Biotechnology. Opportunities for International Development. Synthesis Report Executive Summary*, World Bank, Australian Centre for International Development Assistance Bureau, International Service for National Agricultural Research, Canberra, Australia, 1989; J. Cohen, 'Biotechnology research for the developing world', *Trends in Biotechnology*, Vol 7, 1989, pp 295–303; Centre Technique de Cooperation Agricole et Rurale/Food and Agriculture Organization of the United Nations, Symposium, *Plant Biotechnologies for Developing Countries*, CTA/FAO, Luxembourg, 26–30 June 1989.

tried to keep up with pest resistance. The range of food crops addressed has also expanded to include roots, tubers, cereals and legumes grown by poorer farmers in more marginal areas. But such efforts are providing neither the breakthroughs in yields of the initial rice and wheat programmes nor the methods to address a host of pathogen and environmental challenges to crop yields.

Finally, GR efforts to target specific nutritional deficiencies through crop breeding have so far been stymied as a result of technical difficulties and issues of producer and consumer acceptability. Efforts on the part of the International Maize and Wheat Improvement Centre (Centro International de Mejoramiento de Maiz y Trigo, CIMMYT) to develop a high-lysine maize that would enhance the availability of that amino acid for those reliant on maize for the bulk of their calories is a case in point. Even though High Quality Protein (HQP) maize, the successor to high-lysine maize,[8] incorporates acceptable texture, adhesive and insect-resistance characteristics, its acceptance poses a formidable task: assuring a market for this nutritionally superior product, getting the HQP germplasm into locally adapted maize varieties and monitoring its persistence. Morever, this requires convincing food and nutrition policy makers, who consider calories, not protein, the major nutritional problem of the poor, that additional investment in distributing HQP is worth the effort.

Institutionally, the GR is often taken to be synonymous with a new cluster of international agricultural research centres (IARCs) established to assist national agriculture research programmes in selecting and implementing improved seeds and technologies. In building and collaborating with national research programmes, these IARCs helped LDCs train scientists, establish breeding and agronomy programmes, and monitor ecological and economic conditions in order to establish rational breeding priorities. However, this picture leaves out other important national and international participants, notably bilateral efforts to build national breeding programmes, especially in hybrid maize and sorghum. In addition, GR technologies have always depended on chemical inputs from the private sector, and, in the case especially of hybrid seeds, often on private or parastatal seed industries for germplasm multiplication and distribution. The roles that these institutions will assume in ABT development and technology transfer are crucial in anticipating the roles that ABTs will play in solving or exacerbating hunger in LDCs.

Agricultural biotechnologies

ABT is defined here as the *in vitro* manipulation of whole plant, cellular or molecular materials for the purpose of improving agricultural plants or processes. Table 1 lists the major techniques and some of their applications, crops, and crop characteristics. Improving on conventional breeding, ABTs offer methods to introduce into cultivars of interest alien genes or new combinations of genes for desirable characteristics such as specific pest resistances, environmental tolerances, or nutritional, processing or sensory qualities. ABT also promises to collapse the time necessary for breeding.

Using cell technologies, plant breeders can also screen and select for desirable plant types and then multiply them rapidly by micropropagation to produce uniform clones that possess all the desirable characteris-

[8] National Research Council (US), Ad Hoc Panel of the Advisory Committee on Technology Innovation, Board on Science and Technology for International Development in cooperation with the Board on Agriculture, National Research Council, *Quality-Protein Maize*, National Academy Press, Washington, DC, USA, 1988.

Table 1. Applications of biotechnology in agriculture.

Technique	Level of manipulation (food crop examples)	Comments
Micropropagation (apical meristem culture)	Tissue (onions, apples, potatoes, cherries, lemons)	Enables rapid propagation of superior plants and production of pathogen-free plants. This is the Bt most easily and widely used in LDCs.
In vitro fertilization	Cell (corn, lettuce)	Allows favourable 'wide' crosses by circumventing incompatibility mechanisms to introduce new sources of insect and disease resistance.
Embryo rescue	(barley × rye; barley × wheat; rice; embryo *Oryza sativa* × other rice species)	Allows favourable 'wide' crosses by circumventing incompatibility mechanisms to introduce new sources of insect and disease resistance.
Protoplast fusion	Cell (potato × tomato; cress × turnip)	Non-sexual hybridization circumvents sexual incompatibility barriers.
Anther (microspore, pollen) culture	Cell (used for many plants, eg barley, rice)	Manipulation of chromosome number to increase yields or stress tolerance.
Somaclonal (gametoclonal) variation	Cell (potatoes, tomatoes, sugar cane, onion, celery, carrots, canola, lettuce, rice)	Creates new genetic combinations *in vitro* with improved nutritional quality, stable yield-enhancing characteristics.
In vitro selection	Cell (corn)	Allows selection *in vitro* for increased blight or stress resistance; improved amino acid content.
Gene transformation by Agrobacterium plasmid	Molecular (tomato, potato, lettuce, sunflower, canola, celery, soybean, alfalfa, asparagus, walnut, apple)	Various agronomically useful characteristics determined by single genes have been used to transform these plants, eg resistance to viruses and insects and tolerance of herbicides. Transformation with antibiotic resistance has been achieved in several instances; this has no agronomic value but is used as a marker to indicate transformation.
by microinjection	(rye, canola)	
by protoplast manipulation	(rice, lettuce)	
by high-velocity microprojectiles	(soybean)	
Genetic transformation of endophyte	Bacterial cell (in corn)	Bacteria with *Bacillus thuringiensis* toxin protect host plant.
Restriction length Fragment polymorphism	Molecular (tomato, potato, rice, maize, wheat, vegetable crops)	Allows for mapping and selection of favourable polygenic characters.
Anti-sense	Molecular (tomato)	Inactivates production of certain proteins to allow for durable characteristics such as higher solids content or longer shelf-life.
Diagnostic probes	Molecular (all crops)	Allows definitive and early detection of disease for rapid, targeted pesticide response that minimizes costs, pesticide damage, and crop losses.

tics. At the cellular or tissue level it is also possible to clean away pathogens from vegetatively produced crops and then multiply the planting material rapidly, so that farmers can begin a new season with disease-free cuttings.

In addition to plant-improving technologies, ABTs offer cropping-system improvements through genetically engineered organic management of crop residues, enhanced symbiosis between soil microbes and plants, and multiple-cropping–agroforestry possibilities that promise to restore and maintain soils and provide diverse sources of food and income. Such possibilities are envisaged to be particularly relevant for Africa and those areas of Asia and Latin America in which the GR has either not been implemented or has had a minimal effect. To improve agronomic conditions, for example, approaches include the selection and distribution of rhizobia (soil micro-organisms) to enhance nitrogen contents of soils and the development of a variety of micro-organisms to break down crop residues as sources of fertility or soil conditioners. A third ABT application is the use of micro-organisms and enzymes to modify food and industrial processes, thus modifying the economic value of plants and their products and considerably transforming agricultural markets, trade and prices.

All these potential applications, however, raise important questions for LDCs. In contrast to the GR, ABTs have been developed outside a framework of values and institutions specifically aimed at alleviating food shortage and hunger in poor nations and households (Table 2). Instead, they have been developed first in commercial, then in public contexts, to limit crop losses to pests, possibly to lower the costs of production inputs, and to raise agricultural income for both the suppliers and consumers of ABTs. Widespread commercial application may well increase both food availability and income for hungry populations, but profit-making motivations may limit technology

Table 2. A comparison of Green Revolution and agricultural biotechnology.

	Green Revolution	Agricultural biotechnologies
Priorities	Productivity- and production-increasing technologies oriented to increasing food production in developing countries.	Special characteristics of high-value products; stable yields, cost-reducing technologies, low-input technologies; biological sources of disease and insect resistance.
Structure of research and agenda	Government and international agricultural establishment set priorities.	Private firms, national institutes, and in a few cases international centres control technologies.
Crops	Major food crops, especially wheat and rice, with limited success in other cereal grains, legumes, and root and tuber crops.	Potentially all crops, speciality crops or special characteristics of food crops.
Inputs	Chemical- and energy-intensive and costly; fertilizers, chemical pesticides and herbicides.	Biological environmental control including improved microbial associations, eg mycorrhizas and rhizobia (enhanced N_2 fixation); biological sources of pest resistance; should be less costly and more environmentally sound.
Cropping system type	Mostly monoculture, some farming systems.	Some agroecosystem-specific characteristics.
Regional characteristics	Designed for the most-favoured zones; later more attention to rainfed and less-favoured zones.	Designed for specific problems recalcitrant to conventional plant breeding.

transfer and diffusion, as well as the crops and cropping contexts in which development of ABTs occurs.

Direct private-sector involvement in advancing ABTs reflects a principal difference in the institutional contexts between the GR and ABT and also affects other institutional contexts. In developed countries and LDCs alike, university and research institutes are having to redefine their relationships, with the public agricultural sector on the one hand, and with the private R&D product-oriented sector on the other, as they set their institutional goals and research priorities and adjust their research practices of sharing information and materials to the reality of patenting genes and processes.

IARCs are also having to redefine their roles relative to the national programmes and to the private sector. One approach has been to establish networks oriented around a particular commodity, such as rice, potato or cassava, or a particular technique or characteristic to be addressed by ABT, such as restriction fragment length polymorphism (RFLP) mapping (in rice, maize), virus-resistance, or insect resistance via the bacterial *Bacillus thuringiensis* plant protection protein (Bt). IARCs are also redefining their roles as suppliers of information on legal and economic aspects of ABTs that they might not themselves develop but for which they will negotiate or collaborate with the private sector in developed countries on behalf of LDCs. The specifics of such 'impartial brokerage' roles remain to be detailed, but IARCs may be providing more negotiations and information for informed decision making on accessing cutting-edge technologies, rather than supplying the materials for crop improvement. Nevertheless, they may remain central nodes in the network approach on special commodity-specific problems.[9]

Additional participants in ABT include international donors, such as the World Bank and many agencies of the UN system, and bilateral donors. These donors are still in the process of defining their roles, but almost bimonthly conferences over the past few years on various aspects of ABT and international development have done little to establish coordination of activities, an efficient division of labour, or advisory bodies for LDCs. One of the more advanced efforts, sponsored by the United Nations Industrial Development Organization (UNIDO), is the International Centre for Genetic Engineering and Biotechnology (ICGEB), with laboratories in New Delhi and Trieste. Enmeshed in politics of location and purpose, the scientists set their initial priorities:

[9]L. Sawyer, 'Building bridges of research collaboration through the CGIAR system of centres', pp 13–20 in J.I. Cohen, ed, *Strengthening Collaboration in Biotechnology: International Agricultural Research and the Private Sector*, US Agency for International Development, Washington, DC, USA, 1989; G. Toenniessen and R. Herdt, 'The Rockefeller Foundation's international program on rice biotechnology', pp 291–318 in *ibid*; CIMMYT, *Toward the Twenty-First Century: CIMMYT's Strategy*, CIMMYT, Mexico, DF, 1989; International Rice Research Institute, *IRRI Toward 2000 and Beyond*, IRRI, Manila, The Philippines, 1989.

to improve plant foods not already under intensive study in developed countries and to work on a balanced set of foodplants – one oilseed, one carbohydrate source, one cereal grain and one legume crop.[10] In practice, however, these centres pursue a widely mixed set of priorities – including biofertilizers, waste management and other uses of fermentation technologies – that more closely approximate those of some national biotechnology centres that have tried to address a variety of food, energy, health and economic concerns.

Finally, NGOs are also contemplating becoming actors, as some of the technologies are not so complex or expensive as to preclude their being manipulated by community-level projects and directed towards the benefit of an unusual assortment of crops to diversify income and sustain genetic and environmental resources.[11]

Ultimately, all these participants are deciding what techniques, crops and crop characteristics to use; and, based on existing knowledge, resources and the perceived needs and capabilities of the individual LDCs, they are influencing the choices and developments of ABTs for developing countries.

ABTs for food crops

Progress in expanding the numbers of crops amenable to manipulation has been rapid over the past five years, and scientists have recently succeeded in transforming and regenerating some varieties of the major cereal grains. As we enter the 1990s, however, we are able to manipulate only a handful of genes for useful characteristics – for herbicide tolerance and virus- and insect-resistance. A 1987 survey[12] among European scientists and technologists engaged in ABT activities predicted a 70–80% likelihood that different genetic-engineering steps would be complete for major monocots (corn, rice, wheat, barley) and dicots (potato, canola, soybean, pea, sugar beet) in the next 20 years. But the numbers of traits that would be available to manipulate would still be limited, and perhaps all of these would be those controlled by single rather than multiple genes: herbicide tolerance potentially transferable to all (regeneratable) crops; virus resistance (in dicots such as potato, sugar beet); stem-borer resistance (in maize); fungal-disease resistance (in wheat and barley); and certain nutritionally desirable single-gene characteristics such as improved protein quality (in cereals and legumes) and more favourable triglycerides (in oilseeds).[13]

Important traits thought to involve two or more genes are tolerances for temperature extremes, drought and/or waterlogging, extreme salt, ion or pH soil conditions. Also under polygenic control are such growth-related characteristics as photosynthetic efficiency, overall growth characteristics, general robustness under conditions of minimum input, and receptivity to symbiotic associations with favourable microbes such as nitrogen-fixing bacteria. Genetic markers are the promising avenue of research for polygenic traits, and genetic maps using RFLPs are being constructed for rice, wheat, maize and various vegetable crops. But the utility of these maps will depend on successful linking of the map characteristics to the traits of interest, and on the inherent genetic variability that occurs between varieties of that species. Predictions that ABT will bring about a 10–20% reduction in breeding times by 1997, and 20–30% by 2007,[14] are dependent on breeders' being able to control the traits of interest.

[10]International Centre for Genetic Engineering and Biotechnology, *Biotechnology in Agriculture: Evolving a Research Agenda for the ICGEB*, ICGEB, New Delhi, India, 17–22 September 1985; United Nations Industrial Development Organisation (UNIDO), *Biotechnology for Development*, UNIDO, Vienna, Austria, 1989.
[11]E. Messer, 'How ethnobotany influences the interpretation of biotechnology in developing countries', paper presented at the Thirteenth Ethnobiology Conference, Tempe, AZ, USA, 23 March 1990.
[12]N. Gotsch and P. Rieder, 'Future importance of biotechnology in arable farming', *Trends in Biotechnology*, Vol 7, 1989, pp 29–34.
[13]*Ibid.*
[14]*Ibid.*

Table 3. Green Revolution and agricultural biotechnology compared for rice.

	Green Revolution	Agricultural biotechnologies
Technologies	Conventional breeding.	*In vitro* manipulation/selection to allow for wide crosses or genetic transformation that introduce new desirable genetic variation; marker-based breeding.
Characteristics	Short duration; non-photoperiod sensitive; dwarf, short stiff straw; fertilizer response; later broad genetic resistance to pests and diseases; some attention to flavour; later farming systems research for stable yields under broad range of conditions.	Cold tolerance, specific mineral and ion tolerances, tolerance of drought and waterlogging; specific pest resistances; seedling vigour; nutritional quality (vitamin A; protein).
Regional characteristics	Designed for the most-favoured zones; later more attention to rainfed and less-favoured zones.	Designed for specific problems and zones recalcitrant to conventional plant breeding; some additional improvement of rices for the most-favoured zones.
Institutional coverage	Asia (IRRI) with some attention to Latin America (CIAT) and minimal attention to Africa (IITA WARDA), in each case associated with national rice-breeding programmes.	Rockefeller rice network that includes IRRI, CIAT, South, Southeast and East Asian national agricultural research programmes and research institutes in developed countries and some commercial private researchers.
Impact	Transformed traditional farming systems by new seed/water/fertilizer/chemical regimes sometimes accompanied by mechanization; reduced numbers of landraces; resulted in approximately 100 million metric tons additional rice per annum in Asia and Latin America.	No impact yet, but virus resistance and insect resistance will be ready for application once successful rice transformation systems are widespread; marker-based breeding close.
Ecosystem	Chemical pest control; chemical nutrient supplementation.	Some biological nitrogen fixation through cultivating 'green' fertilizer (*Azolla* and blue-green algae) for rice production.

The availability of these technologies and traits for rice, and the institutions carrying them out, are presented in Table 3 as one set of contrasts of ABT with the GR for a major food crop. Even in rice, however, it is not clear that transformation of all varieties will be routine within the next 10 years, although the potential genetic transformation for resistance to rice tungro virus and to certain insects may be completed. It is also also unlikely that ABT will contribute directly to eradicating vitamin A deficiencies or improving protein intakes among the very young and nutritionally impoverished who consume rice diets. Targeted research to manipulate the carotene synthesis pathway as a strategy to enhance vitamin A content, for example, is not well advanced. Moreover, scientists question whether people will pay the premium to consume yellow rice.

By contrast, tissue-culture techniques to clean and mass-propagate superior planting materials from the tips of apical meristems are relatively well developed for broad-leafed plants but lag for cereal grasses. Plant tissue culture, above other ABTs, has attracted the interest of LDCs, and operations to screen, clean, select and rapidly multiply vegetatively propagated crops of interest are well advanced in many African, Asian and Latin American nations.[15]

Issues for LDCs

ABT is usually viewed as a high-technology enterprise that requires substantial capital investment, but not all ABT techniques are equally capital intensive. Micropropagation, for example, requires little more than a skilled technician and sterile facilities for manipulating and growing the plant materials. Other techniques are also becoming quicker and simpler. Indeed, other inputs that farmers handle, such as pesticides, could become simpler, and perhaps safer, as resistances and production enhancers formerly delivered in chemical forms could be incorporated into seeds. A critical issue is how decisions will be made on what technologies and crops to support.

Viruses, as a case in point, are a major plague of most economic crops, causing visible direct damage and less easily calculated indirect

[15]See, for example, International Federation of Institutes of Advanced Studies, 'International diffusion of biotechnology', in *IFIAS Annual Report 1988–89*, IFIAS, Toronto, Canada, pp 23–38.

damage as viruses render plants more vulnerable to other pests and generally decrease vigour and yield. Scientists at Washington University, St Louis, Missouri, USA, with support from Monsanto, developed a virus-resistant gene coding for virus-coat protein, and introduced it first into tobacco, then tomato – both crops that are easy to transform – and next potato. With the support of the Rockefeller Foundation Rice Biotechnology Network, an approach to tungro-virus resistance in rice is being developed for distribution to ABT programmes in Asian LDCs. Virus resistance in cassava via transformation is also being advanced with the support of an international research network.[16]

The payoffs in these LDC crops will depend on the success of the R&D, and the ability of the IARCs and national programmes involved to take over the research and produce locally adapted virus-resistant materials that can then be widely disseminated and utilized successfully by farmers. An additional challenge will be to get virus resistance into a number of crop cultivars, so that the problem of genetic uniformity and vulnerability is averted. Virus resistance in common garden crops such as tomatoes for both home consumption and commercial sale may also prove important. If farmers can offset losses and so increase their production, opportunities to increase revenue and diversify cropping will improve.

Another issue is who undertakes the original research on the genes and their transfer, and who therefore 'owns' the technologies or their products. Commercial firms are not in business for philanthropy, and the details of arrangements have yet to be worked out for each case. Individuals identified with Monsanto's virus-resistance technology and Crop Genetics International Bt endophyte technology against crop-borers have been instrumental in proposing or establishing networks to adapt their technological advances to the crops and needs of LDC farmers.[17] Nevertheless, it is not clear how patent and licensing issues may be handled once there develops a market for such genetically engineered products.

To use any of these ABT techniques effectively, national programmes must set priorities among technologies, crops and crop characteristics and have some plan that includes establishing facilities, controlling laboratory equipment, attracting and training scientists and technicians, and assuring safe and effective regulation of genetic releases. National ABT plans will also have to provide guidance to link ABT tools to conventional breeding, testing and distribution programmes, as well as likely incentives to coordinate R&D activities between public and commercial sectors. Curiously, none of the many volumes on the potential impacts of ABTs on food systems or on economies more generally adequately addresses the question of who should make and implement decisions regarding R&D and what specific criteria should guide the process. All admit that we do not yet know the possibilities but thereafter reach differing conclusions on what should be done, given such uncertainties, and offer very little advice on who should or will decide on ABT deployments, and little prognosis on where cooperation could occur and where money might come from.

Pro-technology positions such as that of Sasson,[18] while recognizing the many risks and indeterminacies of present knowledge, take the view that LDCs must hurry and catch up – albeit carefully. Others challenge the technological imperative, ask whether these technologies should be developed at all, particularly given a context in which we really do not

[16]The network, which includes Washington University, St Louis/Monsanto, the Rockefeller Foundation, the French Office de la Recherche Scientifique et Technique d'Outre-Mer (ORSTOM) and the US Agency for International Development, links up with the cassava-breeding programme at the International Institute of Tropical Agriculture in Nigeria and potentially the International Centre for Tropical Agriculture-based Advanced Cassava Research Network in Cali, Colombia.

[17]See, for example, R. Beachy, 'Genetic transformations for virus resistance: needs and opportunities in developing countries', pp 156–164 in Cohen, *op cit*, Ref 9; P. Carlson, 'One company's attempt to commercialize an agricultural biotechnology technology', pp 413–422 in *ibid*.

[18]A. Sasson, *Biotechnologies and Development*, UNESCO (CTA), Paris, France, 1988.

understand the full implications, and insist that LDCs must proceed very slowly, if at all, keeping clearly in mind all the uncertainties and risks.[19] At the same time, they express the fear that biotechnology may turn out to be another tool with which the developed countries will try to increase the dependence of LDCs: that biotechnologies may ruin markets for many tropical crops, fail to address problems of LDC 'orphan' crops, or remain a set of tools unaffordable to small farmers. Additionally they fear genetic erosion, the environmental and public health risks of genetic release, and the dehumanizing technological appropriation of all aspects of the food system.[20] Such positions emphasize no benefits, recommend no further proliferation of oversight institutions, and insist that grassroots organizations take charge of these new life-controlling technologies. They suggest that LDCs negotiate for technology improvement, using access to germplasm and 'farmers' rights' as bargaining tactics, but they leave open the question of *who benefits* at local, public or commercial levels from such bargaining. Clearly, most of the specifics regarding what institutions should develop what types of technologies and apply them to varying cropping problems remain to be worked out by nations in consultation with their indigenous regional, local and commercial sectors.[21]

Help beyond the 1990s

Given the current slow progress in ABT, despite early expectations, it is unlikely that plant genetic engineering will contribute much to overcoming hunger in the 1990s. Certain single-gene traits for pest resistance may become available for major crops, and strategies to control major insect competitors, such as locusts and grain stem-borers, may advance by combinations of both conventional and new biotechnologies. But projected advances in most stress-tolerance and pest-resistance traits are unlikely to improve crop production in the next decade. Nevertheless, the institutions that will affect longer-term impacts on LDCs will be taking shape during this period, as will the tools and plans to overcome many current constraints on crop improvement.

More optimistically, developments in tissue culture for cleaning superior planting material in cassava, potatoes and sweet potatoes, basic starchy staples in much of the developing world, are certainly promising. Researchers in crop science at the University of Zimbabwe, Harare, already report a doubling of yields as a result of IARC contributions to elite germplasm and cleaning through tissue culture, and micropropagation and distribution to farmers.[22] More generally, NGOs in LDCs are exploring the possibilities of utilizing tissue-culture techniques to select and mass-propagate a variety of indigenous crops that might add food, income and sustainable agricultural resources to the lives of resource-poor farmers.[23] Additionally, genetic-engineering approaches to minimizing losses to common virus and insect pests may begin to bolster harvests in common garden crops, such as tomatoes, that provide income and food for producers and more and lower-cost food for local consumers. But taken together, the newly emerging ABTs may have little impact over the next 10 years.

Over the next century, by contrast, the impact of ABT on hunger is likely to be considerable, as useful genes are identified and manipulated, as cropping and trade patterns are transformed. Quite apart from

[19]Fowler *et al*, *op cit*, Ref 6.
[20]D. Goodman, B. Sorj and J. Wilkinson, *From Farming to Biotechnology: A Theory of Agroindustrial Development*, Blackwell, New York, NY, USA, 1987.
[21]Fowler *et al*, *op cit*, Ref 6.
[22]A. Robertson and K.E. Sakina, 'A slice of reality from Africa', *Trends in Biotechnology*, Vol 7, 1989, pp 14–15.
[23]Messer, *op cit*, Ref 11.

summaries of ABT techniques or institutional frameworks,[24] there are also the long-wave 'futures' tracts that envisage a host of new interrelated biotechnologies, institutions and forms of social organization leading to a new period and trajectory of agroindustrial diversification, perhaps the next Kondratiev cycle – at least in Africa.[25]

In between these 10-year and 50–100-year perspectives, however, are the next 20–30 years, when transformations of crop plants, movement of genes among them, and new cropping systems are likely to offer to poor farmers and consumers in LDCs opportunities to offset losses and reduce input costs for staple and less usual crops. Over the next 10 years networking and collaboration among public and private institutions to train scientists, make technologies available, and increase knowledge and materials on common crops, can enable nations to undertake expeditious and targeted breeding and propagation of major staples and supplementary food and trade crops. Additionally, both government and non-governmental organizations, in conjunction with more localized social groups and institutions, might tailor research and findings to local needs for food and income, in the context of protecting environmental resources. On the whole, these developments might improve food supply, small-farmer income and nutrition for many currently impoverished in the countryside – if the private firms, or the scientists who lead R&D programmes, make producing more and better-quality food, at lower cost, a priority for the utilization of their research findings.

[24]See, for example, Sasson, *op cit*, Ref 18, and Fowler *et al*, *op cit*, Ref 6.
[25]A. Mabogunje *et al*, eds, *Beyond Hunger in Africa*, James Currey, London, UK, 1990; Juma, *op cit*, Ref 6; R.U. Ayres, *Technological Transformations and Long Waves*, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1989.