TECHNOPOLICY BRIEF 5

KEEPING HUNGER AT BAY: GENETIC ENGINEERING AND FOOD SECURITY IN SUB-SAHARAN AFRICA

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Acronyms

AGERI	The Agricultural Genetic Engineering Research Institute
Bt	*Bacillus thuringensis*
GMO	Genetically Modified Organism
ICGEB	International Center for Genetic Engineering and Biotechnology
ITSC	South African Institute for Tropical and Sub-Tropical Crops
KARI	Kenya Agricultural Research Institute
NBFs	National Biotechnology Funds
NEPAD	New Partnership for Africa's Development
NGO	Non-Governmental Organization
OECD	Organization for Economic Co-operation and Development
R&D	Research and Development
S&T	Science and Technology
UNDP	United Nations Development Programme
UNU-INRA	United Nations University Institute for Natural Resources in Africa
WFP	World Food Programme

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1.0

Introduction

Persistent poor agricultural production and rising food insecurity in sub-Saharan Africa have placed the role of biotechnology and genetic engineering in human development into sharp focus. Growing food insecurity in Ethiopia, Kenya, Malawi, Mozambique, Swaziland, Zambia, Zimbabwe and other countries of the region has stimulated political and public attention on genetic engineering and on potential benefits and risks of genetically modified (GM) crops. More than 20 million people in the eastern and southern Africa are facing starvation.

There is an intense debate whether these countries should accept GM foods as part of the urgently needed aid to stem catastrophic famine and loss of human life as well as associated socio-political consequences. Unfortunately the debate is now founded on old and extreme positions: one that espouses GM crops as the solution to food insecurity and the other that speaks about genetic engineering and its products as the potential source of human destruction. Between the two extremes are complex policy and ethical issues, including:

- food as cultural value
- the relationship between humanity and nature
- equity in accessing food
- the relevance of modern science
- national sovereignty
- ability of African countries to engage in global scientific advances
- public confidence in the scientific enterprise
- public understanding of new technologies, and many others

These issues often emerge but are left unattended by the extreme pro and anti- GM food activists because questions on the role of genetic engineering and causes of food insecurity (particularly in sub-Saharan Africa) are often poorly framed or structured to suit predetermined interests of certain social and economic institutions. The underlying question often is: Are GM foods the solution to food insecurity in developing countries, particularly in Africa? This question is posed because of the tendency to reduce a complex system of science and techniques into a few of its products, and the treatment of food production as a mechanic or inorganic enterprise.

This policy brief seeks to answer a different question: Under what conditions will genetic engineering contribute to stemming the persistent emergence and growth of food insecurity in sub-Saharan Africa? It is about measures that countries in the region may wish to institute to acquire confidence and capability in using genetic engineering to improve food production systems without undermining their social, ecological and economic foundations. The brief is about safe development and application of genetic engineering for food production in the region. It is premised on the view that any consideration of the role and impacts of genetic engineering in Africa should be cast in a broader context of the region's scientific and technological development. Food aid in whatever form will not solve persistent food insecurity in Africa. What the region requires are new forms of scientific and technological enterprises dedicated to improving food production in specific socio-ecological conditions. The next section sets the stage for the rest of the exploration by providing a general overview of food production in the region.

2.0

Food Production and Security in Africa: Genetic, Social and Scientific Endowments

Sub-Saharan Africa has a rich foundation for agricultural production and food security. It has the necessary genetic and social endowments and components of scientific institutions required to marshall new advances in science and technology (S&T) not only to solve the recurring food insecurity but also to contribute to global agricultural development. As a rich genetic base, Africa has some of the world's unique species of plants, animals and micro-organisms. Using plants as an indicator of the region's biodiversity, at least 45,000 higher plant species can be found in the continent.[1] For example, Malawi's forests occupy some 3.6m ha of land area, accounting for 38% of the total area and 97% of this is covered by indigenous species. The Harar Highlands of Ethiopia have 169 types of crops that were once cultivated by local farmers less than 50 years ago. Such a high degree of genetic diversity is however underutilized today. [2] In the mid-1960s the Chagga community of Arusha/Kilimanjaro in Tanzania cultivated 111 crops of which 53 were trees, 29 food crops, 8 weed species and 21 non-woody plants.

In addition to the genetic resources, sub-Saharan Africa has a diverse range of social institutions—clans, tribes, pastoral communities, women groups and many establishments that have rich knowledge of conservation, enhancement and utilization of resources in diverse agro-ecological conditions. An increasing amount of knowledge from these institutions is now harnessed and applied in modern agricultural production and health systems of the industrialized world.

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[1] WCMC, 1992, p. 66.
[2] Getahum, A. 1988, Tropical African Mountains and their Farming Systems, p. 119 in Riley, K.W. et. Al. eds. (1988), *Mountain Agriculture and Crop Genetic Resources*. Aspect Publishing.

Some sub-Saharan African countries have agricultural research institutions with, at least, rudimentary infrastructure and human resources required to generate scientific knowledge and harness technology to contribute to increased food production and security in the region. Recent surveys show that components of modern agricultural research exist in Kenya, Uganda, Zambia, Zimbabwe, South Africa and possibly many other sub-Saharan countries.[3]

Despite the genetic, social and scientific foundations, sub-Saharan Africa continues to experience declining agricultural production and increasing food insecurity since mid-1980s. For example, in 1998 the region saw poor agricultural performance, as crop and livestock production is estimated to have expanded by less than 1% after the marginal decline record in 1997. The share of total exports from agriculture dropped from over 70% in the 1960s to less than 10% in 1998. In 1998 alone Ethiopia's agricultural productivity dropped significantly by roughly 8%. In 1998 the United Nations Development Programme (UNDP) estimated that 48% of the children in Ethiopia, 41% in Eritrea and 36% in Nigeria were malnourished.[4]

Related to the concerns of food insecurity are the increasing poverty, HIV/AIDS epidemics and environmental degradation. More than half of the population in the region lives on less than US$1 per day. Africa, with its rich genetic and cultural diversity, is the poorest continent in the world. This is the paradox that has not been adequately explained by scholars of African development.

Causes of poor agricultural production and food insecurity in sub-Saharan Africa are many, complex and interrelated. They include harsh ecological conditions that make it difficult for poor farmers with limited scientific and technological inputs to produce enough food. Poor and deteriorating physical infrastructure also make it difficult to access and transport food. Many public policies, including land tenure, deny these countries prospects of improving food production and security. In many

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[3] See below an overview of the status of biotechnology in Africa.
[4] UNDP, 1998. *Progress Against Poverty in Africa*. United Nations Development Programme, New York.

countries land tenure arrangements are ambiguous creating disincentives for sustainable agricultural production. Added to these factors is the low and declining investment in agricultural science. Finding lasting solutions to food insecurity will thus require technical and non-technical means. We therefore stress that genetic engineering can only contribute, and indeed significantly, to long-term food security.

3.0

Genetic Engineering and Food Production: Research and Development Outlook

Genetic engineering is a set of powerful tools provided by advances in S&T. The advances enable researchers to analyze the complete sequence of genes in plants, human, animals and microorganisms. The mapping of genes has emerged as a new area of genetic engineering called genomics that has made it possible to complete sequencing genes for rice among several other plants. This technique is providing new genetic information on various traits and functions that are necessary to improve crop production. Related to genomics is proteomics that is largely about cataloguing proteins within living organisms and providing the basis for linking specific genes to specific proteins. Both genomics and proteomics offer new avenues for improving plants' resistance to pests and diseases and tolerance to environmental conditions such as drought, acid soils and floods.

Genetic engineering and the associated scientific developments have been tapped and used to develop new varieties of crops and new traits in livestock and fish. By 2001 more than 70 GM varieties of crops had been developed and registered for commercial cultivation worldwide, including new varieties of cotton, potato, pumpkin, tobacco, tomato and clove. More than 15,000 field trials have been undertaken globally. Today the total area under genetically improved crops is about 45m ha compared to 11m ha four years ago. Eighty percent of the area planted with GM crops is in the industrialized countries with USA and Canada leading. The remaining 15% is found in few developing countries notably Argentina, China, Mexico and South Africa. Most of the global acreage is devoted to GM cotton, soybean, maize and canola targeting insect resistance and herbicide tolerance as the main traits.

In Africa, South Africa and Egypt lead in genetic engineering and the development of GM crops. South Africa has focused on maize, wheat, soybean, lupines, sunflowers and sugarcane, among other crops. The first field trials for GM crops in the country were initiated in 1990, while conditional commercial release permits were granted in 1997. More than 40 field trials of GM crops have been conducted in South Africa and the country has now commercialized insect-resistant GM maize and insect-resistant GM cotton.

Egypt has invested considerably in genetic engineering of potatoes, cotton, maize and tomatoes. The country has at least 3000 scientists active in biotechnology-related fields and more than US$100 million annually allocated to biotechnology R&D projects. Its leading public agricultural research agency, the Agricultural Genetic Engineering Research Institute (AGERI), has conducted genetic transformation of potato, tomato, cucurbits, maize and cotton. It has also mapped the genome of tomato and rapeseed. The Centre for Genetic Engineering and Tissue Culture at Menoufiya University has transferred *Bacillus thuringensis* (Bt) toxin genes into cotton. Recently the Government of Egypt and Monsanto entered into agreement to field test and to subsequently commercialize cotton with the Bollard Bt gene.

On the whole, current genetic engineering efforts have focused on a narrow range of crops and traits. There is less focus on traits, such as drought and virus resistance, and on pulses, vegetables, fodder, among other crops. A large share of innovations in genetic engineering and GM varieties is primarily driven by private industry for developed country markets. The products developed so far have, with few exceptions, not been targeted towards the needs of poor farmers in the developing world, particularly Africa.

4.0

Benefits and Risks of Genetic Engineering

The debate on the benefits and risks of genetic engineering is relatively old and can be traced back to the 1980s.[5] Polarized into two extremes, the debate has intensified with revolutions in the technology as new products, particularly GM foods, begun to get into the marketplace. While extreme proponents of genetic engineering often fail to recognize that some of its products may have risks, those opposed to the technology either ignore or do not understand its potential to contribute to human development.

Like many technologies, some of the products of genetic engineering may cause risks to humans and the environment. There are concerns that introducing GM crop varieties will negatively impact on the environment. A potential problem is that novel genes might be unintentionally transferred by pollination to other plants, including weeds and wild relatives of the crop species. There are fears that such transfers could lead to the development of resistant 'super-weeds', loss of biodiversity within crop species, and possibly, destabilization of entire ecosystems.

Concerns have also been expressed about the risks to human health by food products derived from GM crops, especially where novel genes have been transferred to crops from organisms that are not normally used in food or animal feed products. Those opposed to genetic engineering have suggested that the transfer might introduce previously unknown allergens into the food chain. Controversy was sparked when a gene from a Brazil nut was successfully transferred into a variety of soybean that was being developed for animal feed. It was confirmed that the allergenic

[5] See for example OECD, 1986. Recombinant DNA Safety Considerations. Organization for Economic Cooperation and Development, Paris, France, and Rifkin, J. 1983. Algeny. Viking Press, New York, USA.

properties of the nut were expressed in the soybean. However, the counter-argument was that this case demonstrated the effectiveness of scientific testing for safety. The allergen was specifically tested for during the development process, and from the positive results the product was never developed for commercial use. Scientists further argue that the structure and characteristics of known allergens are well documented, and that testing for possible new allergens is therefore relatively easy.

Clearly, genetic engineering offers new avenues for increasing food production in sub-Saharan Africa. Its potential risks must, however, be assessed and effectively managed. It is a set of new tools to develop drought resistant crop varieties, improve the nutritional quality of crops like sorghum, cassava, millet and sweet-potato, reduce post-harvest crop loses, improve livestock's resistance to disease, and enable farmers to cultivate in saline conditions. Recent assessments (see Quaim 1999), pathogen-free banana plants in Kenya attempt to assess socio-economic benefits of biotechnology in general and genetic engineering in particular. Quaim's *ex-ante* analysis of the impact of pathogen-free banana shows, for the larger farms, that an average yields increase of 93% can be anticipated, and this may increase to 150% for smallholders. The technology in this case has been developed through public/ private partnership involving the Kenya Agricultural Research Institute (KARI), the South African Institute for Tropical and Sub-Tropical Crops (ITSC), and two tissue culture companies.

'Golden' rice is another example of how genetic engineering can be used wisely to contribute to the solution of food insecurity. In this case, genetic engineering has been deployed to develop a rice variety that can produce beta-carotene metabolized into Vitamin A. This new variety has the potential to address the growing problem of Vitamin A that causes partial or total blindness in several million children in Africa each year. The challenge now is to make this variety available to African rice farmers, and possibly to develop it further for African conditions.

5.0

The Way Forward for Africa

How then should African countries respond to the opportunities and challenges posed by genetic engineering? We suggest that these countries should establish broad-based platforms to mobilize the public and scientific communities to build confidence in the technological advances associated with genetic engineering. In addition, they will need to identify their specific national priorities in food production and harness the growing body of science and innovations in genetic engineering to address specific problems. Public research and development (R&D) agencies and policies dedicated to genetic engineering as well as partnerships with private industry will be crucial, and lastly African countries will need to develop and implement regulatory measures to manage any environmental, economic, health and social risks associated with genetic engineering. Below, we explore each action.

Build Public Confidence and Participation

Science in general and genetic engineering in particular are not evolving in a socio-political vacuum. The African public and politicians have (or should have) a direct interest in scientific advances and technological developments associated with genetic engineering, yet they are not participating in the GM debate. Many countries within the region are facing obstacles that hinder the citizens' participation in the debate on the impacts of GM crops and the potential role of genetic engineering in solving food insecurity. Considerable institutional space in the debate has been taken by isolated groups of non-governmental organizations (NGO) opposed to GM crops and purporting to speak for the African rural poor, and groups of scientists who espouse the benefits of the new technology for the poor. It is unlikely that the two groups: anti and pro-GM crops groups have the attention of millions of farmers in Africa. The general public and farmers in particular are not informed about the nature of the technology, its potential benefits and risks, and rarely do they participate in deciding on what crops or problems biotechnology research and development should focus on.

The intensifying debate on GM crops, confusing counter claims from pro and anti-GM activists, and often passive reactions by African governments, is likely to make the public lose confidence in the scientific enterprise and overall decision-making authorities. Processes that will legitimately bring the voices of the public to inform and change the focus and content of the current debate are necessary. Governments and other stakeholders should take the following actions to build public participation and confidence:

(a) *Undertake well-structured and objective assessment of African public perceptions of and/or opinions on genetic engineering and GM products*. Such assessments must be accompanied by organized activities to provide the public with reliable and adequate information on the nature of the technology and its products.

(b) *Have public stakeholders—the youth, women, farmers and other social groups—legitimately represented on bodies that are charged with regulating GM import, development and commercialization*. Currently, it is difficult to determine the legitimate loci of GM decision-making in many countries of sub-Saharan Africa. Even where biosafety frameworks have been developed and adopted (e.g. in Zimbabwe and Kenya), political institutions have ignored them and often made policy pronouncements that are not necessarily founded on science and informed by public opinion. What is required is the review and determination of appropriate decision-making mechanisms. Such mechanisms should have representation from all stakeholders including farmers, consumers, environmentalists and religious bodies.

If genetic engineering is to improve food production in Africa, it should be guided to co-evolve with local, social and economic production systems. Appropriate social and economic institutions will be required to articulate demand for the technology and to act as 'watchdogs' for its responsible application. We are proposing that broad-based platforms that enlarge public confidence in genetic engineering through open participation in priority setting and decision-making are established.

Build and Utilize Public R&D Capacity

To harness and benefit from advances in genetic engineering as well as to manage any risks, African countries need to build a diverse range of human and institutional capacities. They require expertise in molecular biology, biochemical engineering, plant breeding and bioinformatics, among other areas. They also need national agencies or institutes dedicated to the conduct and management of genetic engineering. Currently many African countries do not have such agencies. Their limited investments in genetic engineering and biotechnology tend to be in the form of projects scattered across the institutional landscape. This is in sharp contrast to the organization of biotechnology and genetic engineering activities in Cuba, China, India and the USA where special centers devoted to genetic engineering have been established. It is probably only in Egypt, Nigeria and South Africa where agencies dedicated to biotechnology are found.

It is crucial that each African country identifies and implements measures to build dedicated biotechnology agencies. Such efforts may focus on identifying a few potential national institutes, and providing political support and financial resources for them to grow into national centers of excellence in genetic engineering for food production. National centers of excellence should focus on specific priority problems identified through public participation. They need significant and predictable funding and should have explicit links to the private sector. In addition to research, they should also devote their attention to training scientists in new science fields, such as genomics.

The establishment of national centers of excellence in genetic engineering need to go hand in hand with the creation of appropriate mechanisms to finance R&D. Current funding of biotechnology R&D is still relatively low to enable African countries to effectively engage in genetic engineering. For example, an assessment by Falconi (1999) showed that Indonesia's total expenditure for funding biotechnology R&D in 1985-96 was US$18.7 million while Kenya spent just about US$3.0 million. Nigeria and South Africa are increasing their financial investment in biotechnology and genetic engineering. The Federal Government of Nigeria will provide the National Biotechnology Development Agency with an average of US$ 263 million per year for the next three years as a start-up grant. South Africa's new biotechnology strategy commits more than US$ 300 million per year from government to finance a variety of biotechnology initiatives. Other countries of the region need to invest more in genetic engineering. Some of them may wish to create special funding mechanisms (possibly National Biotechnology Funds (NBFs) for R&D. Such mechanisms would mobilize domestic and international public and private finance to support specific priority research and innovation activities that target the improvement of food production.

Establish and Apply Regulatory Instruments

Many African countries lack coherent regulatory instruments and institutions to manage risks related to genetic engineering. Where instruments have been formulated and adopted by governments, there are weak institutional arrangements for enforcing regulatory procedures. As a result, there is no consensus on how best to respond to global developments in genetic engineering and, particularly, whether to allow the importation and/or development of GM crops. The current controversy over GM food aid to Zambia and Zimbabwe clearly demonstrates the importance for governments to institute and apply regulatory instruments as well as risk assessment and management procedures.

In June 2002 the government of Zimbabwe rejected a consignment of 17,500 tons of maize from the USA because it was not certified free of GM material. The government was concerned that some of the grains would be planted and thus releasing GM into the environment and potentially undermining the country's exports to the European Union and other countries that have banned GM foods.[6] Zambia also rejected GM maize from the USA citing potential human health risks despite the assurance from the US administration that the maize had been tested and proven to be safe.

There are many interest groups, ranging from scientists to activists that are debating whether African countries should accept GM foods. What is of concern is that they have paid little or no attention on how best to use existing national, regional and international regulatory instruments to make informed decisions. Some groups may be exploiting political uncertainty and economic instability, among other situations, to promote narrow agendas that deny the public a choice and to undermine national

6 Zimbabwe's government recently accepted the GM maize after protracted controversy and diplomatic interventions from the USA and the World Food Programme (WFP).

learning from the application of risk assessment and management instruments. In Zimbabwe, for example, the debate acquired an intense political tone and locus of decision-making became full of intense diplomatic interventions denying local scientists and national regulatory authority space to engage in risk assessment. Our survey and consultations with relevant government officials and scientists show that the government did not, in a procedural way, apply provisions of national biosafety regulations. The Research (Biosafety) Regulations—Statutory Instrument 20 of 2000—regulate the development and application of modern biotechnology in general, and genetically modified organisms (GMO) in particular. The law vests responsibility for risk assessment with the National Biosafety Board (established under section 4). This Board did not get an opportunity to conduct scientific analysis of the GM maize offered by the USA.

Risk management and making decisions on the development, importation and use of GM crops are knowledge-intensive responsibilities that require the participation of scientists and consumers. Appropriate regulatory instruments should guide these processes. Such instruments should enable countries to invoke the precautionary principle without denying them opportunities to address short-term and urgent needs, particularly in accessing and providing food to the hungry. They should create institutional arrangements that mobilize domestic and international science to make informed decisions.

There is need to build national capacity to assess and respond to risks and tap benefits generated by genetic engineering. Initiatives such as the capacity building programme of the International Center for Genetic Engineering and Biotechnology (ICGEB) will play a major role in building the capacity of African countries to conduct risk assessment. The ICGEB is engaged in the building of national capacity in industrial, agricultural, pharmaceutical, animal and human health biotechnology. The ICGEB has now more than 30 affiliated centers around the world, some of which have emerged into centers of excellence in genetic engineering.

Build Public-Private R&D Partnerships

A large and growing portion of the scientific information and investments in genetic engineering are held by the private sector mainly in the industrialized world. According to Ernst & Young, for example, in 1997 US companies invested US$9.4 billion in R&D, employed 140,000 people and posted total revenues of US$18 billion. At the same time there were 1,036 European companies working in the life sciences, employing more than 39,000 people directly, with revenues of US$3.1 billion and US$2.2 billion invested in R&D.[7] For public research institutions in Africa to access this information they will need to create strategic links with the private companies in the industrialized countries. The second reason is based on effective commercialization of biotechnology with the participation of private sector. The economic history of public R&D in many parts of the world demonstrates that public agencies have limited capacity to engage in the commercialization of new innovations. They often require private entrepreneurs to take their innovations into the economic domain.

Another good reason is that private biotechnology companies are potential new sources of financial resources for biotechnology R&D in Africa. The historical evolution of biotechnology in the United States, Germany and Japan vividly demonstrates the role of companies as sources of finance for biotechnology R&D. In Japan, companies have financed biotechnology R&D through venture capital and other arrangements. In the USA they have financed university departments and scientists to undertake specific research on contract basis. African countries may wish to explore and exploit financial opportunities associated with partnering with private companies.

[7] See Falconi, C. 1999 for Ernest and Young data.

6.0

Conclusion

Rapid scientific and technological advances associated with genetic engineering and biotechnology offer challenges and opportunities for African countries to address some causes of persistent food insecurity. Tapping these opportunities and confronting the challenges will require knowledge-based platforms for decision-making and increased investment in scientific development. Africa should eschew either the pro or anti- GM foods sentiments and erect scientific and technological foundations for harnessing benefits of the new science while at the same time reducing risks. It is through their own investment in genetic engineering that they are able to make informed decisions on which specific GM crops to import or accept as part of any food aid. Furthermore, with increased investment in genetic engineering that targets specific food production challenges, the region may be able to build the basis for food security: reducing dependency on food aid. Africa requires genetic engineering as part and parcel of its endogenous scientific and technological development.

References

Avramovic, M. 1996. *An Affordable Development? Biotechnology, Economics and the Implications for the Third World*. Zed Books, London.

Brenner, C. and Komen, J. 1994. *International Initiatives in Biotechnology for Developing Country Agriculture: Promises and Problems*. Development Centre Studies, OECD, Paris.

Brenner, C. and Komen, J. eds., 1996. *Integrating Biotechnology in Agriculture: Incentives, Constraints and Country Experiences*. Report of a Policy Seminar for West Asia and North Africa. International Service for National Agricultural Research (ISNAR).

Bunders, J. ed. 1990. *Biotechnology for Small-Scale Farmers in Developing Countries*. VU University Press, Amsterdam.

Falconi, C. 1999. 'Agricultural Biotechnology Research Indicators and Managerial Considerations in Four Developing Countries', p. 24-37 in Cohen, J.I. ed. 1999. *Managing Agricultural Biotechnology—Addressing Research Program Needs and Policy Implications*. CAB International.

Farrington, J. 1989. *Agricultural Biotechnology: Prospects for the Third World*. Overseas Development Institute, London.

Fransman, M. 1991. *Biotechnology: Generation, diffusion and policy, An Interpretive Survey*. UNU/INTECH Working Paper No. 1.

Juma, C. 1989. *The Gene Hunters: Biotechnology and the Scramble for Seeds*. Zed Books, London.

Juma, C., J. Mugabe, and P. Kameri-Mbote, eds. 1995. *Coming to Life: Biotechnology in African Economic Recovery*. Nairobi: Acts Press (in press).

Kenney, M. 1986. *Biotechnology: The University-Industrial Complex*. New Haven, Yale University Press.

Komen, J. 1999. 'International Collaboration in Agricultural Biotechnology', p. 110-127 in Cohen, J.I. ed. 1999. *Managing Agricultural Biotechnology—Addressing Research Program Needs and Policy Implications*. CAB International.

Krimsky, S. 1982. *Genetic Alchemy: The Social History of the Recombinant DNA Controversy*. MIT Press, Boston.

Mugabe, J. 2000. *Biotechnology in Developing Countries and Countries with Economies in Transition: Strategic Capacity Building Considerations*. United Nations Commission on Science and Technology for Development and United Nations Conference on Trade and Development (UNCTAD), Geneva, Switzerland.

OECD 1989. *Technology and Global Competition: The Challenge for Newly Industrializing Countries*. Organization for Economic Cooperation and Development: Paris.

Orsenigo, L. 1989. *The Emergence of Biotechnology*. Pinter Publishers, London.

OECD, 1998. *Biotechnology and the Changing Role of Government.* Organization for Economic Co-operation and Development, Paris, France.

OTA 1992. *Biotechnology in a Global Economy*. Office of Technology Assessment of the United States of America, Washington DC.

Sasson, A. 1988. *Biotechnologies and Development.* United Nations Educational, Scientific and Cultural Organization (UNESCO).

UNCTAD. 1990. *Transfer and Development of Technology in Developing Coun-tries: A Compendium of Policy Issues*. New York: United Nations Conference on Trade and Development.

United Nations. 1963. *Science and Technology for Development: Report on the United Nations Conference on the Applications of Science and Technology for the Benefit of the Less Developed Areas*. New York: United Nations.

United Nations (1992), *Agenda 21*. Report of the United Nations Conference on Environment and Development.

United Nations 1992. *Biotechnology and Development: Expanding the Capacity to Produce Food*. Unite Nations, New York.

Warhurst, A. 1989. *New Directions for Empirical Policy Research in Biotechnology*. Paper presented at the International Symposium on Biotechnology for Sustainable Development, March 1989, African Centre for Technology Studies, Nairobi.

Wiegele, T. 1991. *Biotechnology and International Relations: The Political Dimensions*. University of Florida Press, Gainesville.

World Commission on Environment and Development (WCED) 1987. *Our Common Future*. Oxford: Oxford University Press.

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