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INTRODUCTION

Biotechnology represents an important set of tools that developing countries could use to raise crop productivity, enhance pest and disease resistance, adapt crops to new or adverse ecological conditions, enhance the nutritional content of foods, reduce post-harvest food losses, and create market for specialty products. Crops of relevance to temperate regions, where their benefits are being documented, have dominated the early stages of the development of biotechnology.[1] It is not unusual for new products and processes to emerge in "centers of technological origin" in the industrialized countries.[2] The issue therefore is identifying the forces that influence the ability of the developing countries to make use of emerging technologies. Current trends in agricultural biotechnology reveal that regulatory uncertainty in international trade has become one of the most critical obstacles to the use of biotechnology to meet the needs of developing countries.

1. BIOTECHNOLOGY AND HUMAN NEEDS

The role of science and technology in globalization is currently at the center of a wide range of international controversies involving pharmaceuticals, foods and software. The debates stem partly from the fact that science and technology is currently viewed in the industrialized countries as a major tool for international competitiveness.[3] But this view

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1. See Gianessi, L., C. Silvers, S. Sankula, J. Carpenter. (2002). *Plant Biotechnology: Current and Potential Impact for Improving Pest Management in US Agriculture: An Analysis of 40 Case Studies*. Washington, DC: National Center for Food and Agricultural Policy; Pray, C., J. Huang, R. Hua, S. Rozelle. (2002). "Five Years of Bt Cotton in China—The Benefits Continue," *Plant Journal*, 31: 423-430.
2. For a review of the history of agricultural biotechnology in the United States, see Juma, C. and Calo, M. (2002). "Government and Technological Innovation: The Case of Agricultural Biotechnology in the United States". In Norberg-Bohm, V. (ed.) *The Role of Government in Technology Innovation: Insights for Government Policy in the Energy Sector*. Cambridge, Massachusetts, USA: Belfer Center for Science and International Affairs, Kennedy School of Government, Harvard University.
3. Archibugi, D., J. Howells, J. Michie. (1999). "Innovation Systems and Policy in a Global Economy", In Archibugi, D., Howells, J. and Michie, J. (eds.), *Innovation Policy in a Global Economy*. Cambridge, UK: Cambridge University Press, pp. 1-15.

has emerged concurrently with growing recognition of the necessity to use emerging technologies to address the needs of the poor in developing countries. Current uses of science and technology apparently conflict with the expectations of a large section of humanity not able to afford basic requirements such as essential medicines, nutritional options and energy.[4]

Social movements and groups around the world are therefore questioning the role of new technologies in meeting the needs of the poor.[5] They contend that new technologies have helped to widen the gap between the rich and the poor within and between nations. Others have gone as far as suggesting that modern technological innovations are a source of social, economic and ecological problems facing developing countries. There is a general mood of suspicion, caution and hostility towards technological innovation worldwide, often fueled by a wide range of social movements.[6] This general questioning of technology is reflected in global debates over access to its products.

The debate over agricultural biotechnology has so far focused on international trade in GM foods.[7] Attempts to resolve the growing concerns through the 1992 United Nations Convention on Biological Diversity (CBD) dealt largely with environmental aspects of living modified organisms (LMOs).[8] Issues related to human health, especially those pertaining to human health, are being negotiated under the Codex Alimentarius Commission administered by the Food and Agriculture Organization and the World Health Organization.[9] Other bodies in the United Nations systems are handling different aspects of the biotechnology debate. For example, the United Nations Commission on Science and Technology for Development is examining issues related to biotechnology capacity building in developing countries. The United Nations Conference on Trade and Development (UNCTAD) is looking into the trade-related aspects of biotechnology.[10] Despite these efforts, the debate has so far focused largely on the risks associated with biotechnology and sidestepped its potential benefits in developing countries.

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4. United Nations Development Programme (2001). *Human Development Report*, Oxford, UK: Oxford University Press.

5. Juma, C. *et al*. (2001). "Global Governance of Technology: Meeting the Needs of Developing Countries", *International Journal of Technology Management*, 22(7/8): 629-655.

6. Social movements working in the field of environment tend to attribute ecological degradation to technological change. Other groups concerned attribute cultural decay to technological change and still others argue that technological change is a source of unemployment. Although there is some truth in these claims, the reality is more complex and defies simplistic attributions of the kinds that dominate popular discourse.

7. Pardo, R., C. Midden, J.D. Miller. (2002). "Attitudes Toward Biotechnology in the European Union", *Journal of Biotechnology*, 98: 9-24; Priest, S.H. (2000). "US Public Opinion Divided Over Biotechnology?" *Nature Biotechnology*, 18(9): 939-942; Macer, D., M.A.C. Ng. (2000). "Changing Attitudes to Biotechnology in Japan", *Nature Biotechnology*, 18(9): 945-947.

8. The Cartagena Protocol on Biosafety to the Convention on Biological Diversity was adopted on 20 January 2000 in Montreal and has so far been ratified by over 45 countries and will come into force upon the 50th ratification. Article 1 of the protocol states: "In accordance with the precautionary approach contained in Principle 15 of the Rio Declaration on Environment and Development, the objective of this Protocol is to contribute to ensuring an adequate level of protection in the field of the safe transfer, handling and use of living modified organisms resulting from modern biotechnology that may have adverse effects on the conservation and sustainable use of biological diversity, taking also into account risks to human health, and specifically focusing on transboundary movements."

9. The commission was set up in 1961 to administer food safety and quality standards.

10. See, for example, Zarrilli, S. (2000). *International Trade in Genetically Modified Organisms and Multilateral Negotiations: A New Dilemma for Developing Countries*. Geneva: United Nations Conference on Trade and Development.

Ironically, initial policy discussions over biotechnology in the late 1980s focused largely on its potential applications to meeting the needs of developing countries.[11] Governments negotiated and signed the CBD based on detailed consideration of potential role of biotechnology in development. Article 16(1) of the Convention on Biological Diversity provides the basis for international cooperation in the field of biotechnology:

> "Each Contracting Party, recognizing that technology includes biotechnology, and that both access to and transfer of technology among Contracting Parties are essential elements for the attainment of the objectives of this Convention, undertakes subject to the provisions of this Article to provide and/or facilitate access for and transfer to other Contracting Parties of technologies that are relevant to the conservation and sustainable use of biological diversity or make use of genetic resources and do not cause significant damage to the environment."

Indeed, developing countries argued that they could use their biological resources to create new industries using the emerging technology.

In addition to the CBD, the role of biotechnology in development is clearly articulated in Chapter 16 of Agenda 21, the program of work of the 1992 United Nations Conference on Environment and Development. According to Chapter 16 of Agenda 21, biotechnology:

> "promises to make a significant contribution in enabling the development of, for example, better health care, enhanced food security through sustainable agricultural practices, improved supplies of potable water, more efficient industrial development processes for transforming raw materials, support for sustainable methods of afforestation and reforestation, and detoxification of hazardous wastes. Biotechnology also offers new opportunities for global partnerships, especially between the countries rich in biological resources (which include genetic resources) but lacking the expertise and investments needed to apply such resources through biotechnology and the countries that have developed the technological expertise to transform biological resources so that they serve the needs of sustainable development. Biotechnology can assist in the conservation of those resources through, for example, ex situ techniques."

The promises of these international commitments remain unrealized, largely because biotechnology has increasingly been defined in terms of its risks and little consideration has so far been given to finding mechanisms that offer a balanced assessment of its potential.[12] This has partly been because of the absence in most developing countries of science and technology policies that clearly articulate the importance of biotechnology as an essential aspect of development.[13] Enterprises in developed countries have in turn been slow to engage in technological partnerships in developing countries because of concern

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11. Juma, C. (1989). *The Gene Hunters: Biotechnology and the Scramble for Seeds*. Princeton, New Jersey, USA: Princeton University Press.
12. Juma, C. (2000). *Science, Technology and Economic Growth: Africa's Biopolicy in the 21st Century*. Tokyo: United Nations University Press.
13. Consequently, international organizations such as the United Nations are only starting to explore the role of science and technology in international development. See, for example, National Research Council (2002). *Knowledge and Diplomacy: Science Advice in the United Nations System*, National Academy of Sciences, Washington, DC.

over the lack of a policy environment that supports the use of emerging technologies.[14] Efforts to place biotechnology in a risk frame have gone hand in hand with concerns over globalization.[15] In other words, trade and technological competition have provided the context in which international debates over biotechnology need to be examined.[16]

It is therefore not a surprise that the first international regime regulating biotechnology—the Cartagena Protocol on Biosafety—deals mainly with trans-boundary movement of LMOs, which is a euphemism for "international trade".[17] Calling for the recognition of the trade-related aspects of these debates does not in any way seek to diminish the importance of environmental and human health concerns. These are indeed critical and need to be addressed in their own right and should be taken seriously.[18] But focusing only on these issues mystifies more fundamental underpinnings of the debate and is unlikely to resolve the issues.

The rules and decision procedures set out under the Cartagena Protocol are designed to regulate international trade and have inspired a wide range of analyses that examine its relationship with the World Trade Organization (WTO).[19] Follow-up negotiations on international regulation of biotechnology now focus on issues such as labeling and traceability, which are also trade-related issues.

Some consumers in industrialized countries continue to express skepticism towards transgenic foods. This is partly because they have a wide range of foods from which to make the necessary choices. They therefore question the need to use new technologies to make incremental changes in their foods without offering tangible benefits, especially those that help to improve human welfare. Indeed, industrialized countries already face challenges associated with excessive production of food. Many of these countries have put in place policies that seek to link food production with environmental conservation.

Industry in the developed countries is looking into ways to producing foods that are relevant to the consumer. Fields such as 'nutraceuticals' and 'functional foods' are emerging as a response to the growing concern among consumers about their health and well being in general. The success of such investments is still in doubt but it is evident that the concerns in industrialized countries stem from the view that meeting food

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14. Rausser, G., Simon, L. and Ameden, H. (2000). "Public-Private Alliances in Biotechnology: Can They Narrow the Knowledge Gaps Between Rich and Poor?" *Food Policy*, 25(4): 499-513.
15. Paarlberg, R. (2000). "The Global Food Fight", *Foreign Affairs*, 79(3): 24-38.
16. Sharp, M. (2000). "The Science of Nations: European Multinationals and American Biotechnology", *International Journal of Biotechnology,* 1(1): 132-151; Bijman, J. and Joly, P.-B. (2001). "Innovation Challenges for the European Agbiotech Industry", *AgbioForum*, 4(1): 4-13.
17. Cors, T. (2002). "Biosafety and International Trade: Conflict of Convergence?" *International Journal of Biotechnology*, 2(1/2/3): 27-43.
18. National Research Council (2002). *Environmental Effects of Transgenic Plants: The Scope and Adequacy of Regulation*. Washington, DC: National Academy Press; Wolfenbarger, L. and Phifer, P. (2000). "The Ecological Risks and Benefits of Genetically Engineered Plants", *Science,* 290: 2088-2093.
19. Article 2(4) of the Cartagena Protocol calls for consistency between the protocol and other international treaties: "Nothing in this Protocol shall be interpreted as restricting the right of a Party to take action that is more protective of the conservation and sustainable use of biological diversity than that called for in this Protocol, provided that such action is consistent with the objective and the provisions of this Protocol and is in accordance with that Party's other obligations under international law."

security is no longer the concern of consumers. Much of the consumer interest is shifting to the quality of the food they consume and its contributions to improved health.

The situation in many developing countries—especially in Africa—is different. Low-income families in these countries are faced with a wide range of challenges that include malnutrition, hunger and related illnesses. Addressing these challenges requires deployment of the available technological options. The poor often rely on a limited range of food sources and as ecological degradation continues, the capacity to meet their needs diminishes. Raising agricultural productivity while promoting sustainable land use becomes a key development goal. Indeed, in many poor regions of the world agricultural production is done by women who also have other critical household responsibilities.

Responding to these challenges requires investment in technologies that are appropriate to the needs of low-income communities living in diverse ecological zones often located in areas that are not served by major markets. Agricultural production in these areas will need to be equally diverse and to reflect local needs and preferences. Genetic modification and the emerging techniques of genomics offer the possibility to design farming systems that are responsive to local needs and reflect sustainability requirements. In other words, genetic modification and genomics make it possible to design farming systems that are decentralized, responsive to local needs and more productive than existing methods.

2. DIVERGENT TECHNOLOGICAL TRAJECTORIES

The capacity to modify living organisms to perform new functions offers humanity the potential to make the transition from classical farming methods to decentralized production systems that are consistent with ecological principles. It is because of this adaptive potential that developing countries have been particularly interested in building capacity in this field. Let us take the African region as an example. The green revolution only partially touched this continent. Advances in maize breeding helped to extend the scope of food production in many countries. Efforts in other areas showed dismal results. There are many reasons for this. First, the cold war concerns that inspired the Green Revolution in Latin America and Asia took on a different character in Africa.[20] Raising food productivity was not a strategic way of responding to superpower competition in the region. As a result, promoting agricultural research was not given the kind of priority that it received in other regions.

The Green Revolution relied on a long history of prior research and accumulated knowledge on corn, wheat and rice and focused on limited technical tasks such as raising yields using increased inputs. Africa's food consumption patterns did not lend themselves to large-scale use of these crops. Africa lacked the institutional foundations for research in these crops. Subsequent efforts to create research institutions that focused on tropical crops have not registered the same levels of productivity gains and impacts as wheat, rice

20. Perkins, J. (1997). *Geopolitics of the Green Revolution: Wheat, Genes, and the Cold War*. Oxford, UK: Oxford University Press.

and corn. In fact, the fate of these institutions now hangs in the balance, as international assistance to tropical agriculture declines and most international agricultural institutions fail to keep up with the demands of a changing global knowledge system.

There are, however, other ecological factors that set Africa apart from other continents. Much of the continent is arid or semi arid and marked by ecological diversity.[21] These variations are associated with mosaics of productive activity with limited scope for the kind of mass agricultural production that has been promoted in other regions of the world. Agricultural research to meet the needs of isolated rural populations was beyond the reach of traditional plant breeding institutions. Moreover, the sheer diversity of crops used in the region and the absence of large markets undermines the feasibility of approaches adopted during the Green Revolution.

Today's technological capabilities in fields such as genomics make it possible to adapt crops to these diverse ecosystems in ways that are consistent with the principles of sustainable agriculture. Herbicide resistance, disease and stress tolerance and other traits can be applied to promote sustainable agriculture in regions that do not support agriculture today. It is this technological flexibility and the creation of niche markets that developing countries hoped to use to improve their farming methods and reduce pressure on the environment. But the evolution of biotechnology has taken a different path with a focus on markets of the industrialized world or the temperate regions. This is partly because of the logic of technological agglomeration that favors the accumulation of knowledge in areas with previous investments in technological capabilities and supportive institutions. Developing countries that need biotechnology most are also the ones least involved in its development.

Table: 1: Global coverage of transgenic crops by country, 2001 (Million Ha)

USA	35.7
Argentina	11.8
Canada	03.2
China	01.5
South Africa	00.2
Australia	00.2
Mexico	<0.1
Bulgaria	<0.1
Uruguay	<0.1
Romania	<0.1
Spain	<0.1
Indonesia	<0.1
Germany	<0.1

Source: James, C. (2002) *Global Review of Commercialized Transgenic Crops: 2001*. Ithaca, New York: International Service for the Acquisition of Agri-Biotech Applications.

21. Conway, G. (2003). *From the Green Revolution to the Biotechnology Revolution: Food for Poor People in the 21st Century*. Director's Forum. Washington, DC: Woodrow Wilson International Center for Scholars.

The use of transgenic crops has been expanding rapidly, but this diffusion has been in the temperate regions (Table 1). Most of this coverage is in large farms where genetic modification has been used to introduce incremental changes in existing crops.[22] These incremental adjustments in crops explain why the distribution of transgenic crops is limited to geographical areas with similar ecological conditions.

Transgenic applications are used mainly in crops such as soybean, corn, canola and cotton. The bulk of the crops contain traits for herbicide tolerance and disease resistance. These trends show that the early diffusion of transgenic crops has been largely in the temperate regions and has been limited to a few major commercial crops. The promise of biotechnology to meet the needs of low-income families in the developing world still remains a distant dream.

Table 2: Transgenic food crops being tested in developing countries: a sample

Beans	Potato
Cabbage	Rape
Cauliflower	Rice
Chili	Soybean
Maize	Squash
Melon	Strawberry
Mustard	Sugarcane
Papaya	Sweet potato
Peanut	Tomato
Pepper	Wheat

Source: Toenniessen, G., J.C., O'Toole, J. DeVries. (2003). Advances in Plant Biotechnology and its Adoption in Developing Countries. *Current Opinion in Plant Biology*, 6 (1-8).

There are two main reasons why the promise has not been realized. First, crop development for low-income families has traditionally been carried out by the public sector. But biotechnology has emerged from the private sector, which lacks the incentives to invest in crops for poor people.[23] Second, agricultural research in the public sector has been declining over the years. It is unlikely that the situation will change without a redirection of existing research priorities in private enterprises through the provision of appropriate incentives, as well as a significant increase in public sector funding for agricultural research.[24] In addition, institutional arrangements will need to be created to facilitate closer cooperation between private and public-sector institutions.

22. Juma, C. (2000) "The UN's role in the new diplomacy", *Issues in Science and Technology*, XVII(1):37–38.
23. Pingali, P.L., G. Traxler. (2002). "Changing Locus of Agricultural Research: Will the Poor Benefit from Biotechnology and Privatization Trends?" *Food Policy*, 27: 223-238; Byerlee, D., K. Fisher. (2002),. "Accessing Modern Science: Policy and Institutional Options for Agricultural Biotechnology in Developing Countries," *World Development*, 30(6): 931-948.
24. Pray, C., D. Umali-Deininger. (1998). "The Private Sector in Agricultural Research Systems: Will it Fill the Gap?" *World Development*, 26(6):1127-1148.

The divergence in technological evolution is likely to be reinforced by three factors. First, the continuing uncertainty over market access for GM products in Europe will reduce the pace of technological innovations in products intended for international markets.[25] Indeed in the short-run, premium markets now exist for non-GM crops. This general trend could discourage investment in biotechnology research and as a consequence slow down technological development in developing countries. Secondly, developing countries that are engaged in biotechnology are likely to redirect their efforts towards meeting local needs. Many of the products of developing countries are destined for local consumption, partly because of urgency in this field and partly because of uncertainty in international markets.[26] Third, a number of biotechnology firms in the industrialized world are willing to share their technology on condition that it is used to address local food needs and not in export crops. Several enterprises have granted royalty-free uses of their inventions for the development of rice enhanced with vitamin A, on condition that the product is grown only by farmers earning less that $10,000 a year. Monsanto has licensed its technology to Kenya royalty-free for use in the development of virus-resistant sweet potatoes for local consumption.

3. REDIRECTING TECHNOLOGICAL EFFORT

Efforts to redirect biotechnology to address the needs of low-income families in developing countries should be placed in a large policy framework that addresses other social issues. More importantly, such strategies should be part of policies designed to use science and technology to achieve sustainable development goals.[27] In addition, biotechnology should be considered as one of the tools in a larger portfolio of technological options. In this regard, biotechnology is simply a set of tools and the embodied knowledge needed to solve specific problems. How this is done depends largely on the choice of problems and nature of institutional arrangements in which the technology is issued. Efforts that seek to curtain the diffusion of biotechnology therefore limit the ability of developing countries to design technological mixes that suit their specific circumstances.

This view does not imply that technology is neutral. The choice of technological trajectories often reflects the economic, social and cultural context in which it emerges. Use of technology does not always reproduce the same conditions that characterized its origins. Technologies are often modified and adapted to reflect new socio-economic conditions, depending on prevailing social goals. Indeed, it is the flexibility that is embodied in biotechnology techniques that makes it possible for them to be applied under different farming systems. It is true that biotechnology is currently used mainly in large-

25. Phillips, P., D. Buckingham. (2001). "Agricultural Biotechnology, the Environment, and International Trade Regulation", In Michelmann, H.J., J. Stabler, G. Storey. (eds.) *Globalization and Agricultural Trade Policy*. Boulder, Colorado, USA: Lynne Rienner Publishers, pp. 67-96; Sheldon, I.M. (2002). "Regulation of Biotechnology: Will We Ever 'Freely' Trade GMOs?" *European Review of Agricultural Economics*, 29(1): 155-176.
26. Toenniessen, G., J.C., O'Toole, J. DeVries (2003). Advances in Plant Biotechnology and its Adoption in Developing Countries. *Current Opinion in Plant Biology*, 6(1-8).
27. Juma, C. (2002). "The Global Sustainability Challenge: Fom Agreement to Action", *International Journal on. Global Environmental Issues*, 2(1/2): 1–14.

scale agriculture in the USA. But it is also true that the same technology is being used in small-scale agriculture in China, Mexico, India, South Africa and Kenya. What matters is therefore the choice of farming systems.

The choice of technology should be driven by the determination of local needs. Many developing countries have already indicated in their various agricultural development priorities that could be addressed using genetic modification. Many African countries, for example, lie in regions where drought-tolerance, disease resistance and crop yield increases are priorities. Crops such as cassava, millet, yams, millet and sorghum are prime candidates for genetic modification. Modifications that seek to prolong the shelf life of foods could have a significant impact on reducing post-harvest losses. The use of herbicide tolerance in low-till agriculture is another area of priority, especially in helping to lessen farm labor and providing farm workers—most of whom are women—with opportunities to engage in other activities.

Another potential area for biotechnology application is the development of livestock tolerant to tropical diseases and stresses. Modern methods such as genomics could be applied in this area without requiring genetic modification. Also related to agricultural production is the significance of re-vegetation in marginal areas. Investment in fast-growing plants could help facilitate ecological restoration in many denuded regions of the world. Such research could also help fulfill the fodder requirements of these countries.

Redirecting global research and development efforts to focus on these challenges will entail considerable international cooperation, increases in public sector funding and incentives for private enterprises. It will also take the creation of an atmosphere that is tolerant to the use of emerging technologies in implementing sustainable development goals. But where international cooperation is not possible, bilateral responses that might include realignments in international trade relations will become the only option open to countries that view biotechnology as strategic to their mutual interests. Such a scenario is already emerging under bilateral cooperation arrangements being signed between countries with strong biotechnology-based industries.

Many developing countries are reluctant to engage in biotechnology development because they fear some industrialized countries would erect barriers against their products. These concerns are real and have fostered an atmosphere of distrust that is likely to undermine not only the global trading system, but also the ability of developing countries to meet their human needs.

BIOGRAPHICAL SKETCH

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Professor Juma has won several international awards including the Pew Scholars Award in Conservation and the Environment (1991), the United Nations Global 500 Award (1993) and the Henry Shaw Medal (2001). He holds a PhD in Science and Technology Policy Studies from the Science Policy Research Unit at the University of Sussex (UK). He is Visiting Professor at the Institute for Advanced Study of the United Nations University (Tokyo) and the University of Strathclyde (UK). He is Editor of the *International Journal of Technology and Globalization* and Associate Editor of the *International Journal of Biotechnology*.

He was a member of the Gulbenkian Commission on the Restructuring of the Social Sciences and several other international initiatives. He serves or has served on the governing and advisory bodies of several international organizations including World Resources Institute and the United Nations University's Institute for New Technologies.

Professor Juma has written widely on issues of science, technology and environment. His works include *Long-Run Economics: An Evolutionary Approach to Economic Growth* (Pinter, 1987); *The Gene Hunters: Biotechnology and the Scramble for Seeds* (Princeton University Press and Zed Books, 1989); *Innovation and Sovereignty: The Patent Debate in African Development* (African Centre for Technology Studies, 1989); *Coming to Life: Biotechnology and African Economic Recovery* (Acts Press and Zed Books, London, 1994) and *Economic Policy Reforms and the Environment: Africa Experiences* (UNEP, 1995), *In Land We Trust: Private Property, Environment and Constitutional Change* (Initiatives Publishers and Zed Books, London, 1996) and *Science, Technology and Economic Growth: Africa's Biopolicy in the 21st Century* (United Nations University, 2000).